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# CARBONIFEROUS ROCKS OF OUACHITA MOUNTAINS[1]

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## ABSTRACT

The Carboniferous rocks of the Ouachita Mountains are a great succession of sedimentary strata, chiefly shale and sandstone. They present two different sequences or facies: one of these is revealed in the belt lying between the Ti Valley and Choctaw faults along the northwest margin of the Oklahoma structural salient and the other is revealed in all portions of the Ouachita region south and east of the Ti Valley-Choctaw belt. The only rocks here assigned a Mississippian age are included in the Caney shale. They measure a few hundred feet in thickness and all their exposures in the Ouachita Mountains are confined to the Ti Valley-Choctaw belt.

The Pennsylvanian rocks are 18,000–20,000 feet in thickness in most parts of the Ouachita Mountains and if the thickness of the younger Pennsylvanian rocks in the adjoining Arkansas Valley be added, the total reaches about 25,000 feet. Thus, the thickest known section of Pennsylvanian rocks in the United States is revealed in the Ouachita Mountains and the Arkansas Valley.

A portion of the Carboniferous sequence that is exposed south and east of the Ti Valley-Choctaw belt has been assigned various ages in the past. The units, so variously classified, are as follows, the oldest being named first: the Hot Springs sandstone, the Stanley shale, the Jackfork sandstone, and the boulder-bearing shale (formerly designated Caney shale but now designated Johns Valley shale). These units measure altogether about 12,000 feet in thickness. The faunal and floral evidence obtained by the writer and other geologists in recent years indicates that the formations just mentioned are Pennsylvanian in age. This age assignment makes it possible for the writer to reach a more satisfactory conclusion than he has been able to reach hitherto concerning the nature and origin of the boulder-bearing shale. Available evidence appears to indicate that the boulders were transported by submarine land slips from fault scarps on an early Pennsylvanian uplift in southeastern Oklahoma. This uplift is now largely, if not entirely, concealed underneath the northwestwardly overthrust western portion of the Ouachita Mountains.

[1] Read before the Association at the Dallas meeting, March 24, 1934. Manuscript received, May 21, 1934. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

## PURPOSE OF PAPER

The chief purposes of the present paper are to discuss the age relations of the Carboniferous rocks of the Ouachita Mountains and to offer an interpretation of the origin of the boulder-bearing shale of Pennsylvanian age. Progress has been slow and difficult in making definite age assignments for some of the formations because of the scarcity of fossils in them and also because of the complicated folding and faulting to which the rocks have been subjected.

Just as conclusions concerning many problems of the Ouachita region have been changed from time to time in the past, so will present interpretations be affected by future results. Some will be verified, some will be modified, and some will doubtless be discarded.

The attraction of geologists to the region has been accelerated in the last decade by the publication during this period of the Oklahoma and Arkansas state geologic maps[3] and also several reports that describe for the first time the geologic features of the entire region.

Geologists who have devoted much time to field studies in the Ouachita Mountains include G. H. Ashley, A. H. Purdue, L. S. Griswold, J. A. Taff, E. O. Ulrich, C. W. Honess, Sidney Powers, B. H. Harlton, and the writer. The writer's field studies in the region began in 1907 and have continued to the present, but since 1927 there has not been an opportunity for him to visit the region for periods of more than a few weeks each year. The age relations and other problems of the region are so commanding in their interest that they continually fire the enthusiasm of the field worker, and there has been a constant urge to return to the field to extend these studies into areas not previously visited and to re-examine some critical exposures for possible re-interpretations.

For the writer's field studies in Oklahoma use has been made of the excellent manuscript maps by J. A. Taff of the McAlester, Windingstair, Tuskahoma, Antlers, and Alikchi quadrangles. These maps, which cover most of the Ouachita region in Oklahoma, show the structural features and the distribution of the formations including the boulder-bearing shale, and they were used several years ago in the compilation of the colored geologic map of Oklahoma that was issued in 1926 by the United States Geological Survey.

## GENERAL FEATURES OF CARBONIFEROUS ROCKS

The Carboniferous rocks of the Ouachita Mountains are a great succession of sedimentary strata, chiefly shale and sandstone. The

[3] H. D. Miser, *Geologic Map of Oklahoma, U. S. Geol. Survey* (1926). G. C. Branner, *Geologic Map of Arkansas, Arkansas Geol. Survey* (1929).

sediments were derived mostly from the Paleozoic land Llanoria of Louisiana and eastern Texas and they were deposited not only in the portion of the geosynclinal basin that is now revealed in the Ouachita Mountains, 220 miles long and 50–60 miles wide, but also in the portions of the geosynclinal belt now concealed beneath the deposits of Cretaceous and Tertiary age in the Gulf Coastal Plain. The Ouachita Mountains form the northern culmination of a great arc in the geosynclinal belt. The southwest portion of the arc extends from the Ouachita Mountains of Oklahoma in a southwesterly direction into Texas and thence past the east side of the Central Mineral region. The southeast limb of the arc appears to extend from the Ouachita Mountains of Arkansas in a southeasterly direction across Mississippi toward Alabama. This geosynclinal trough adjoined the northern margin of the hinterland Llanoria and the portion of it extending from Oklahoma into Texas has been designated the Llanoria geosyncline by E. H. Sellards.[4] To the writer it seems that this term is appropriately applicable to the entire geosynclinal belt that adjoined Llanoria. The portion of the belt in Oklahoma and Arkansas has, however, been designated the Ouachita geosyncline by the writer as well as other authors. A foreland area of deposition lay northwest of the geosynclinal belt.

The Carboniferous rocks of the Ouachita Mountains are chiefly Pennsylvanian in age; only a few hundred feet are Mississippian. The Pennsylvanian rocks measure 18,000–20,000 feet in thickness in most parts of the Ouachita Mountains and if the thickness of the younger Pennsylvanian rocks in the Arkansas Valley be added, the total reaches about 25,000 feet. Thus, the thickest known section of Pennsylvanian rocks in the United States is revealed in the Ouachita Mountains and the Arkansas Valley.

The Carboniferous rocks in the Ouachita region, together with the rocks of Cambrian, Ordovician, Silurian, and Devonian age, were much faulted and closely folded by a series of movements beginning about the middle of the Pennsylvanian and continuing until late in the Pennsylvanian. They have been subdivided into several formations which are listed in Table I, giving the sequences in different portions of the Ouachita Mountains and the Arkansas Valley.

Two somewhat different sequences of Carboniferous rocks appear to be represented within the Ouachita Mountains. One of these is revealed in the belt between the Ti Valley and Choctaw faults in

[4] E. H. Sellards, "The Pre-Paleozoic and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. of Texas Bull. 3232* (1932), p. 23.

TABLE I

SEQUENCES OF CARBONIFEROUS ROCKS EXPOSED IN DIFFERENT PORTIONS OF OUACHITA MOUNTAINS AND ARKANSAS VALLEY

(Names of formations and thicknesses in feet are given)

| | | ARKANSAS VALLEY | | OUACHITA MOUNTAINS | | |
|---|---|---|---|---|---|---|
| | | *Oklahoma* | *Arkansas* | *Ti Valley-Choctaw Belt of Oklahoma* | *Area South and East of Ti Valley-Choctaw Belt* | |
| | | | | | *Oklahoma* | *Arkansas* |
| Carboniferous | Pennsylvanian | Boggy shale.....2,000–3,000<br>Savanna sandstone.....750–2,000<br>McAlester shale..1,150–2,500<br>Hartshorne sandstone.....100–200<br>Atoka formation..2,000–7,800 | Savanna sandstone.....1,000<br>Paris shale, Fort Smith formation, and Spadra shale 1,375–1,625<br>Hartshorne sandstone.....100–300<br>Atoka formation.7,800+<br>Jackfork sandstone.....1,000+ | Atoka formation*7,000+<br>Wapanucka limestone .....0–800<br>Springer formation.....0–500+ | Atoka formation.7,000<br>Johns Valley shale†.....0–1,000+ (boulder-bearing)<br>Jackfork sandstone.....6,000<br>Stanley shale....6,000–10,000 | Atoka formation 6,000<br>Johns Valley shale‡.....0–500+ (boulder-bearing)<br>Jackfork sandstone.....5,000–6,600<br>Stanley shale...6,000<br>Hot Springs sandstone...0–200 |
| | Miss. | | | Caney shale.....0–200 | | |
| Devonian | | | | Woodford chert (Dev.?)<br>Pinetop chert§ (Dev.) | Arkansas novaculite (lower part, Dev.; upper part, Dev.?) | Arkansas novaculite (lower part, Dev.; upper part, Dev.?) |

* The Atoka appears to succeed the Caney shale in the few areas where the Caney is exposed.

† The Johns Valley shale in Oklahoma is present only along the northwest margin of this area.

‡ The Johns Valley shale in Arkansas is present only near Boles, on the north margin of the Ouachita region.

§ The Pinetop chert is named from Pinetop School, Sec. 5, T. 2 N., R. 15 E., in Ti Valley, Oklahoma. Exposures near school reveal about 50 feet of fossiliferous chert and limestone of Onondaga age. Name displaces Brushy Creek chert of E. O. Ulrich (*Oklahoma Geol. Survey Bull. 45*) which is preoccupied by Brushy Creek limestone of Pennsylvanian age in Illinois.

Oklahoma. The other sequence is widely exposed in all portions of the remainder of the Ouachita region (Fig. 1).

### CARBONIFEROUS SEQUENCE IN TI VALLEY-CHOCTAW BELT

The Ti Valley-Choctaw belt, 5–8 miles in width, is crescent-shaped and lies along the frontal or northern margin of the Oklahoma structural salient[5] of the Ouachita Mountains (Fig. 1). The belt thus adjoins the portion of the Ouachita area that has been thrust farthest northwest. The amount of horizontal thrusting that seems to have taken place along the Ti Valley fault has been estimated by the writer to be 20 miles or more (Fig. 2). This structural complexity has made the stratigraphy of the Ti Valley-Choctaw belt more difficult of solution than any other portion of the Ouachita Mountains. The complete solution is far from attained. Certainly not all the faults have yet been discovered and possibly the exposures of the Caney shale, the Woodford chert (Devonian?), and the Pinetop chert (Devonian) are windows in overthrust sheets. Most of the area that has been mapped as the Atoka formation on the Oklahoma geologic map appears to be designated properly by that name, but there is the possibility that exposures of Jackfork sandstone will be recognized later within the areas that have been mapped as Atoka. Also, other units will perhaps be recognized in the Ti Valley-Choctaw belt.

The Woodford chert is revealed at several places, including Wesley, Brushy Creek, and Bengal. It is composed of interbedded chert and shale, both of which are black when unweathered. Phosphatic concretions are abundant. The chert is, in the writer's opinion, equivalent to the middle and upper members of the Arkansas novaculite, as developed in Arkansas and northern McCurtain County, Oklahoma. The chert is doubtfully referred by the writer to the Devonian but it is regarded by E. O. Ulrich, C. L. Cooper,[6] and others as Mississippian in age.

The Caney shale is exposed near Ti and Wesley post offices and Brushy Creek. It is black platy hard shale with black limestone concretions and small black spherical phosphatic concretions an inch

[5] H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull.* 50 (1929), pp. 23–25.

———, "Oklahoma Structural Salient of the Ouachita Mountains," *Jour. Washington Acad. Sciences*, Vol. 23 (1933), pp. 110–12.

———, "Some Problems of the Ouachita Mountains," *Tulsa Geol. Soc. Digest* (1933), pp. 35–38.

[6] C. L. Cooper, "Some Conodonts from the Arkansas Novaculite, Woodford Formation, Ohio Shale, and Sunbury Shale," *Jour. Pal.*, Vol. 5 (1931), pp. 143–51, Pl. 20.

———, "New Conodonts from the Woodford Formation of Oklahoma," *ibid.*, pp. 230–43.

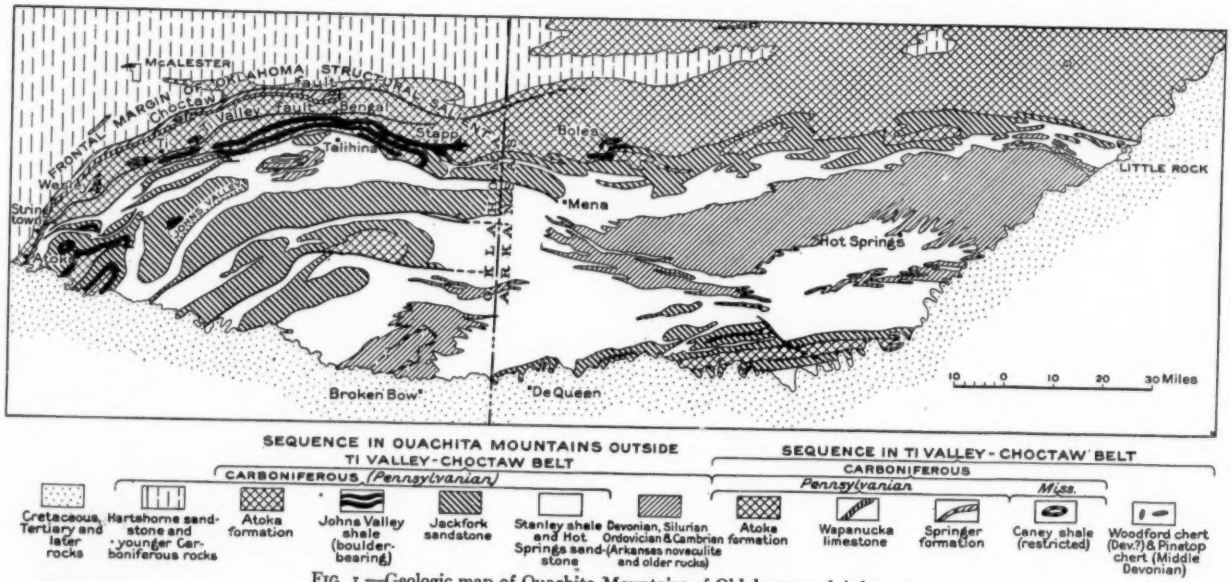


FIG. 1.—Geologic map of Ouachita Mountains of Oklahoma and Arkansas.

or less in diameter. The shale rests with unconformity on the Woodford chert, as is shown by a conglomerate at its base. The invertebrate fauna consisting of *Goniatites*, *Caneyellas*, and other forms constitute the Caney fauna of Mississippian age that has been described by G. H. Girty.[7] From the fauna he concludes that the Caney is equivalent to the sequence in the southern Ozark region, that includes the Moorefield, Batesville, and Fayetteville formations. Carey Croneis,[8] who has made a recent study of the fauna of the Fayetteville shale, concludes that the Caney shale is "the correlative of the Moorefield and Batesville formations, and the lower limestone and lower shale of the Fayetteville, but the Wedington sandstone and the upper shale are younger sediments."

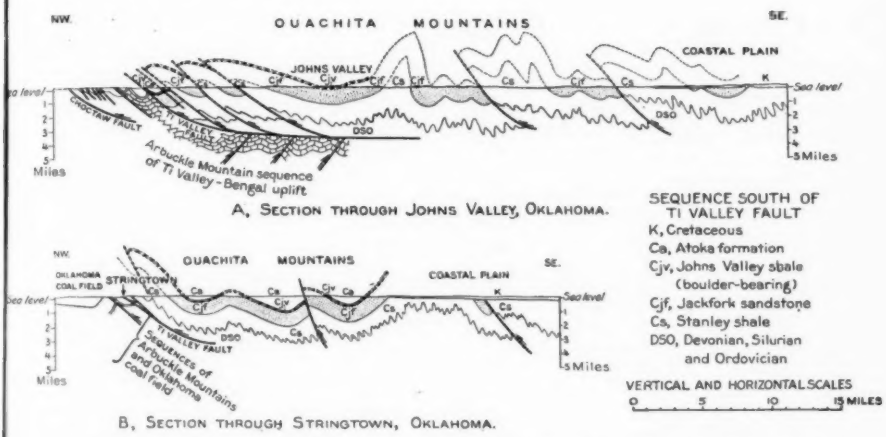


FIG. 2.—Two structure sections across western portion of Oklahoma structural salient, showing folding and faulting of rocks. Section A shows hypothetical structure of Arbuckle Mountain sequence that has been largely, if not entirely, concealed by northwestward overthrust of rocks above Ti Valley fault.

The Springer formation is revealed in narrow belts bounded by faults on the north and by exposures of the Wapanucka limestone on the south, but at no place is the base of the formation revealed. The full thickness of the Springer is therefore not known. Also, the nature of the rocks immediately underlying it is not known. Presumably,

[7] G. H. Girty, "The Fauna of the Caney Shale of Oklahoma," *U. S. Geol. Survey Bull. 377* (1909).

[8] Carey Croneis, "A New Type of Paleontologic Table," *Amer. Jour. Sci.*, 5th ser., Vol. 20, No. 119 (November, 1930), pp. 339–43.

however, the Springer is underlain by the Caney shale just as it is in the Ardmore basin and as equivalent rocks on the north side of the Arbuckle region are underlain by a Mississippian shale. The Springer is composed of bluish black clay shale and some beds of hard gray calcareous fine-grained sandstone. Clay ironstone concretions are abundant in some portions of the shale. Relatively few fossils are present. If the Springer is present in the vicinity of the Wesley, Brushy Creek, and Ti Valley exposures of the Caney shale, it has not been recognized thus far. Beds that are mapped as the Atoka formation succeed the Caney in those localities.

The Wapanucka limestone, next above the Springer, is composed chiefly of limestone, but includes shale and sandstone. As determined by both B. F. Wallis[9] and the writer, the proportion of sandstone increases eastward and makes higher and higher ridges in that direction. In the vicinity of LeFlore, Oklahoma, the limestone disappears. Eastward beyond that village the sandstone and shale of the Wapanucka have been mapped as the basal portion of the Atoka formation. The Wapanucka does not appear to extend southward to the south side of the Ti Valley-Choctaw belt. Perhaps it grades laterally into the Atoka in that direction just as it does toward the east. G. H. Girty,[10] K. F. Mather,[11] and G. D. Morgan,[12] who have studied the fauna of the Wapanucka limestone, point out the close similarity of the fauna to that of the Morrow group of Pottsville age in the southern Ozark region. From the fossils the conclusion is that the Morrow and Wapanucka are at least partially equivalent.

The Atoka formation, which is next above the Wapanucka limestone, consists of shale and sandstone in varying proportions. The shale is a black clay shale and predominates. The sandstone is fine-grained and brown and occurs in both thin and thick beds, some of which form mountain ridges. The thickness is indeterminable, because of close folding and faulting and also because no rocks assignable to a younger formation have been recognized in the area. At Wesley, Brushy Creek, and Ti the Atoka rests on the Caney shale,

[9] B. F. Wallis, "The Geology and Economic Value of the Wapanucka Limestone of Oklahoma," *Oklahoma Geol. Survey Bull. 23* (1915), pp. 53–66.

[10] G. H. Girty, "The Relations of Some Carboniferous Faunas," *Proc. Washington Acad. Sciences*, Vol. 7 (1905), p. 10.

[11] K. F. Mather, "The Fauna of the Morrow Group of Arkansas and Oklahoma," *Scientific Laboratories Denison Univ. Bull.*, Vol. 18 (1915), p. 83.
———, "Pottsville Formations and Faunas of Arkansas and Oklahoma," *Amer. Jour. Sci.*, 4th ser., Vol. 43 (1917), pp. 134–35.

[12] G. D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2* (1924), pp. 56–62.

but at Bengal and other localities it is in direct contact with the Woodford chert. Possibly there is a hiatus at the base representing all or a portion of the Springer formation and Wapanucka limestone. Also there is a possibility that the base may be a folded fault plane through which erosion has cut downward and formed windows revealing the Caney, Woodford, and Pinetop formations. David White states that the Atoka formation, on the basis of plants obtained in the vicinity of Atoka, Oklahoma, is upper Pottsville.[13]

CARBONIFEROUS SEQUENCE OUTSIDE TI VALLEY-CHOCTAW BELT

The portion of the Ouachita Mountains outside the Ti Valley-Choctaw belt is 220 miles long and 50–60 miles wide, thus constituting the major portion of the region. The Pennsylvanian rocks here revealed are 18,000–20,000 feet in thickness. Rocks of Mississippian age appear to be absent unless, as will be discussed more fully, they are represented in the upper part of the Arkansas novaculite.

The Arkansas novaculite crops out in several large areas. The largest of these is a wide belt extending west-southwest from Little Rock, Arkansas, into Oklahoma. Two isolated areas of exposure in Oklahoma are the Potato Hills and Black Knob Ridge. Fossils found thus far in the novaculite comprise fossil wood, conodonts, and linguloids.[14] These have all been obtained from the middle division of the formation in Arkansas and from the upper part of the formation in Oklahoma. The lower division of the formation, as shown by fossil evidence discovered by C. W. Honess,[15] is Middle Devonian in age, but the higher beds in the formation are here tentatively assigned a Devonian age, although some geologists hold that they and the equivalent formations, the Woodford and Chattanooga formations of Oklahoma, are Mississippian.

The Hot Springs sandstone rests unconformably on the Arkansas novaculite, as is indicated by a thick conglomerate at the base of the sandstone and by the varying thicknesses of the top beds of the novaculite. All the known exposures of the sandstone occur in and near the city of Hot Springs, Arkansas. The sandstone is absent at most places in Arkansas and is not present in Oklahoma.

[13] Memorandum dated June 30, 1932.

[14] H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), p. 58.
C. L. Cooper, "Some Conodonts from the Arkansas Novaculite, Woodford Formation, Ohio Shale, and Sunbury Shale," *Jour. Pal.*, Vol. 5 (1931), pp. 143–51, Pl. 20.
———, "Conodonts from the Upper and Middle Arkansas Novaculite at Caddo Gap, Arkansas," *Bull. Geol. Soc. Amer.* Vol. 44 (1933), p. 211.

[15] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923), p. 117.

The Stanley shale and the Jackfork sandstone are the two most widely exposed formations of the Ouachita Mountains. The extent of their distribution, as indicated by exposures, is apparently the same for the two formations. They are present everywhere in the mountains south and east of the Ti Valley fault. They appear to be equivalent to the Springer formation of the Ti Valley-Choctaw belt.

An unconformity probably separates the Stanley shale from the Arkansas novaculite at all places where the Hot Springs sandstone does not lie between them. It is indicated not only by a widely distributed conglomerate at the base of the Stanley, but also by the absence of the novaculite in a few places in Arkansas.

The clastic materials composing the shale and sandstone of the Stanley and Jackfork came from a land mass south or southeast from the Ouachita region. This is shown by the northwestward thinning of the sandstone beds in both formations and by the northward disappearance of grit in the Jackfork. Beds of volcanic ash or tuff, as much as 90 feet thick, lie near the base of the Stanley shale in McCurtain County, Oklahoma, and Polk County, Arkansas, in the southern portion of the Ouachita Mountains. They thin out northward and also the size of their component fragments and grains decreases in this direction. The conclusion therefore seems justified that the volcanic materials of the tuffs were ejected from some vent or vents connected with diastrophism of the old Paleozoic land Llanoria on the south and southeast at the beginning of Pennsylvanian time. The deformational movements of the old land beginning with this volcanic activity were profound, as is indicated by the 18,000–20,000 feet of early Pennsylvanian sediments (Stanley, Jackfork, and Atoka) that were derived from it. This thickness of sediments was deposited not only in the portion of the Ouachita trough in the Ouachita Mountains, but vast thicknesses appear to have been deposited also in the adjoining Arkansas Valley and in the southwestward and southeastward continuations of the geosynclinal belt from the Ouachita Mountains.

The fossils from the Stanley shale and Jackfork formations and their age indications are discussed on pages 986–92.

The boulder-bearing Johns Valley shale, until recently designated as Caney shale by most geologists, is widely exposed in a crescent-shaped belt 17 miles wide and 125 miles long in the northwest part of the Ouachita Mountains. It extends from the west end of the mountains near Atoka, Oklahoma, eastward to Boles, Arkansas. The shale is absent southeast of the afore-described belt. At its type locality—Johns Valley (formerly called Caney Basin or Cove) in

upper Cane Creek Valley, 10 miles north of Kosoma, Oklahoma—the shale rests on the Jackfork sandstone. This relation appears to hold for all other exposures of the shale (Fig. 1).

A full description of the many features of the shale, including its age and the erratic boulders, is given under another heading, beginning on page 992.

The Atoka formation rests on the Johns Valley shale where that is present, but elsewhere it overlies the Jackfork. It is composed of shale and sandstone in varying proportions. Other features of the formation, including its fossils and basal conglomerate, are described on pages 978–79, 982, 1002, 1007.

### CARBONIFEROUS SEQUENCE IN ARKANSAS VALLEY

The Carboniferous rocks of the Arkansas Valley in Oklahoma and Arkansas belong entirely to the Pennsylvanian series and contain workable coal beds. As is indicated in Table I, several formations with the indicated thicknesses are recognized. Of these there are two, the Jackfork sandstone and Atoka formation, that are found in both the Arkansas Valley and the Ouachita Mountains. The character of the shale and sandstone of which they are composed is the same both in the Arkansas Valley and in the adjoining portion of the Ouachita region. The two exposures of the Jackfork sandstone in the Arkansas Valley are on the crests of two anticlines.

### AGE RELATIONS OF CARBONIFEROUS ROCKS

#### FORMER AGE ASSIGNMENTS

The ages that have been assigned to the Carboniferous rocks of the Ouachita Mountains have differed widely; and they have been changed from time to time as new evidence has become available. Naturally age assignments have been based on stratigraphic relations and on fossil evidence, but progress toward reaching a satisfactory classification has been slow, because of the scarcity of fossils and also because of the complicated faulting and folding of the rocks.

Many of the classifications that have been proposed for the Carboniferous sequence have been influenced by interpretations of the evidence provided by the boulder-bearing shale (Johns Valley shale) lying between the Jackfork sandstone, below, and the Atoka formation, above. Not all classifications have, however, been affected by the boulder-bearing shale, because the shale is restricted to the northwest portion of the Ouachita Mountains and because it was not observed by geologists until the late nineties, when it was mapped by J. A. Taff. Furthermore, the significance of the many faunas of differ-

ent ages provided by the boulders has been interpreted differently. This has resulted chiefly from the small number and limited extent of the exposures of the boulder-bearing shale that are found widely scattered in a rough mountainous country.

In 1892 L. S. Griswold,[16] the author of the first report describing in considerable detail the Arkansas portion of the Ouachita Mountains, applied the term Lower Carboniferous to the sandstones and shales to which the names Hot Springs sandstone, Stanley shale, and Jackfork sandstone have been applied more recently; but he appears to have used the term Lower Carboniferous synonymously with the designation Lower Coal Measures, which was used[17] a few years later by J. C. Branner and G. H. Ashley.

In 1897 the same designation, Lower Coal Measures, was applied by N. F. Drake[18] to the Carboniferous sequence exposed in the northern portion of the Ouachita region in Oklahoma. The names now applied to the section that is exposed in that region are the Stanley shale, Jackfork sandstone, Johns Valley shale, and Atoka formation.

The first report to apply geographic names to the geologic units of the Carboniferous sequence of the Ouachita Mountains is the Atoka folio[19] which was issued in 1902. Also, it was the first report to appear in which the faunas of the erratic boulders were interpreted in such a way that they affected the age assignments of the portion of the geologic section underneath the boulder-bearing shale. In that folio the Stanley and Jackfork formations were classed as Ordovician on the assumption that the scattered exposures of the limestone boulders represent a limestone bed of Ordovician age belonging in a normal stratigraphic succession. The discovery that the limestone exposures do not represent parts of a bed, but that they reveal erratic masses embedded in a shale in a Carboniferous succession approximately 12,000 feet above its base was made in 1904 by E. O. Ulrich in collaboration with J. A. Taff.[20]

[16] L. S. Griswold, "Whetstones and the Novaculites of Arkansas," *Arkansas Geol. Survey Ann. Rept. for 1890*, Vol. 3 (1892), pp. 203–06. Also, Hot Springs and Mount Ida sheets.

[17] J. C. Branner, "Thickness of the Paleozoic Sediments in Arkansas," *Amer. Jour. Sci.*, 4th ser., Vol. 2 (1896), pp. 229–36.
G. H. Ashley, "Geology of the Paleozoic Area of Arkansas South of the Novaculite Region, with an Introduction by J. C. Branner," *Proc. Amer. Philos. Soc.*, Vol. 36 (1897), pp. 217–48.

[18] N. F. Drake, "A Geological Reconnaissance of the Coal Fields of the Indian Territory," *Proc. Amer. Philos. Soc.*, Vol. 36 (1897), pp. 361–72.

[19] J. A. Taff, "Description of the Atoka Quadrangle," *U.S. Geol. Survey Geol. Atlas U.S., Atoka Folio 79* (1902).

[20] J. A. Taff, "Some Erratic Boulders in Middle Carboniferous Shale in Indian Territory." Abstract, *Science*, new ser., Vol. 21 (1905), p. 225.

The view commonly held for the next 23 years (1904–1927) was that the Caney shale of the Arbuckle region represented a westward extension and overlap of the Caney shale that is exposed in the portion of the Ouachita region south of the Ti Valley fault. In the Arbuckle region the Caney rests at places on the Woodford (Devonian?) chert and at other places on the Sycamore limestone (Mississippian). The opinion prevailed that the hiatus at the top of the Sycamore represents "the time during which some 10,000 to 15,000 feet of Stanley shale and Jackfork sandstone were deposited in the near-by Ouachita synclines."[21]

In 1909 A. H. Purdue[22] extended the terms Stanley shale and Jackfork sandstone from Oklahoma into Arkansas and he placed them doubtfully in the Pennsylvanian. The age assignment appears to have been influenced by the opinion of Ulrich who then regarded these formations as Pennsylvanian.

C. W. Honess,[23] in his studies in McCurtain and adjoining counties in Oklahoma, assigned a Pennsylvanian age to the Jackfork sandstone and doubtfully assigned this age to the Stanley shale. These conclusions were based on available fossil evidence and on stratigraphic relations and were not influenced by any consideration of the boulder-bearing shale, which is not present in most of the area studied by him.

In 1927 the age relations of the Carboniferous rocks of the Ouachita Mountains were discussed by C. W. Honess and the writer.[24] The tentative conclusions stated were that the boulder-bearing Caney shale (so designated by Honess and Miser at that time but now designated Johns Valley shale) contains beds of both Pennsylvanian

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E. O. Ulrich, "Fossiliferous Boulders of the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927), pp. 5–6.

[21] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), pp. 527–28 and Pl. 29. For expressions of similar opinions see also
G. H. Girty, "The Fauna of the Caney Shale of Oklahoma," *U.S. Geol. Survey Bull. 377* (1909), pp. 5–14, and
H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 44* (1927).

[22] A. H. Purdue, "The Slates of Arkansas," *Arkansas Geol. Survey* (1909), p. 48 and Pl. 4 opposite p. 40.

[23] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923).
———, "Geology of Southern Leflore and Northwestern McCurtain Counties, Oklahoma," *Bur. Geol. Cir. 3* (1924).

[24] H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 44* (1927).

and Mississippian age, and that the Stanley, Jackfork, and Hot Springs formations are Mississippian in age. The assignment by them, as well as other geologists, of a Mississippian age to these rocks was based almost altogether on the assumption that shale containing a Mississippian fauna[25] was deposited on top of the Jackfork sandstone (Fig. 3 A).

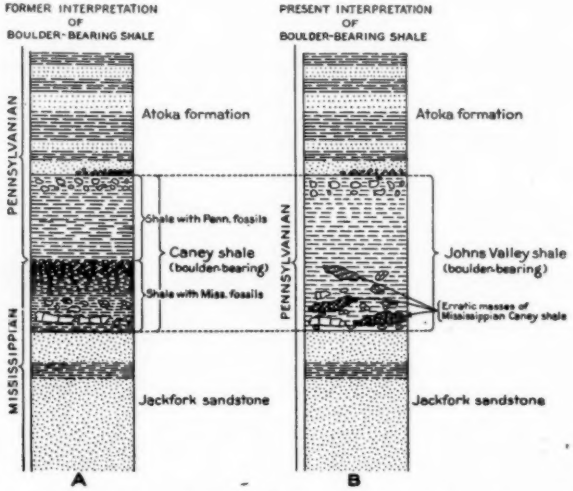


FIG. 3.—Diagrammatic sections showing former and present age interpretations of boulder-bearing shale of Ouachita Mountains.

Also in the same paper Honess and the writer discussed the significance of the large fauna of Morrow age that had been collected and described by Honess.[26] Its stratigraphic position he had earlier placed between his Lower Jackfork sandstone and his Upper Jackfork sandstone. Honess and the writer visited together in 1923 the fossil localities in the northwest corner of McCurtain County, Oklahoma, and their joint conclusions are here stated.[27]

For several reasons (enumerated below) the present writers believe that the "Upper Jackfork" sandstone should be given the name Atoka sandstone and the "Lower Jackfork" is the same as the true Jackfork sandstone. The

[25] G. H. Girty, "The fauna of the Caney Shale of Oklahoma," *U.S. Geol. Survey Bull. 377* (1909).

[26] C. W. Honess, "Geology of Southern Leflore and Northwestern McCurtain Counties, Oklahoma," *Bur. Geol. Cir. 3* (1924).

[27] H. D. Miser and C. W. Honess, *op. cit.*, p. 21.

reasons for the classification of the Upper Jackfork as Atoka and the Lower Jackfork as Jackfork are as follows:

1. The beds that contain the Morrow fauna in McCurtain County are correlated by Honess with the Wapanucka limestone.
2. These fossiliferous beds underlie the "Upper Jackfork" sandstone just as the Wapanucka underlies the Atoka.
3. The "Upper Jackfork," 6,000 feet thick, has a thickness similar to that of the Atoka in near-by areas to the north in Oklahoma where the thickness is between 6,000 and 7,000 feet and also similar to that in Arkansas where the thickness ranges from 6,000 to 7,800 feet.
4. The "Lower Jackfork" has not only the same lithology as the true Jackfork in near-by areas, but also the same thickness.
5. The "Lower Jackfork" is underlain by the Stanley shale just as the true Jackfork is underlain by the Stanley.

The age designations adopted tentatively in the article by Honess and the writer accord with the age assignments (Fig. 3 A) in all the reports[28] on the Ouachita region in which the writer has participated as author or joint author until the present. In these reports the fossil evidence and the stratigraphic relations were interpreted in the same way as they were by Honess and the writer in their joint paper.

In 1927 Ulrich offered before the Tulsa meeting of The American Association of Petroleum Geologists, a new interpretation[29] concerning the boulder-bearing shale to which he then, as well as previously,[30] assigned a Pennsylvanian age. He not only described in detail the erratic boulders, but he concluded that the invertebrate fauna that he previously thought to be Pennsylvanian is in reality Mississippian, as Girty[31] had stated it to be. He concluded that the Mississippian fossils themselves are erratic just as the limestone masses are erratic. In addition he applied the name Johns Valley to the boulder-bearing shale and restricted the term Caney shale to the exposures of the Mississippian shale that contains the well-known Caney fauna as described by Girty. All the exposures of this shale are found in Oklahoma, being confined to the Arbuckle Mountains and the Ti Valley-Choctaw belt.

[28] Some of the reports are here cited:
A. H. Purdue and H. D. Miser, "Description of the Hot Springs District, "*U. S. Geol. Survey Geol. Atlas U.S., Hot Springs Folio 215* (1923).
H. D. Miser, *Geologic Map of Oklahoma, U.S. Geol. Survey* (1926).
H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U.S. Geol. Survey Bull. 808* (1929).

[29] E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

[30] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), pp. 476–77, 527–28, and Pl. 29.

[31] G. H. Girty, "The Fauna of the Caney Shale of Oklahoma," *U.S. Geol. Survey Bull. 377* (1909).

### NEED FOR FURTHER FOSSIL EVIDENCE

Because of the diverse interpretations arising in 1927 among many geologists concerning the structural and historical geology of the Ouachita region, the efforts for obtaining fossil evidence from the boulder-bearing shale and also from the Stanley and Jackfork formations were redoubled by Sidney Powers, B. H. Harlton, and the writer beginning in that year.

Additional plant and invertebrate fossils were collected by the writer from the Jackfork sandstone. The search for plant fossils was extended to the southern Ozark region with the hope that floras might be found in the uppermost rocks of Mississippian age and in the lowermost rocks of Pennsylvanian age of that region. The search in that region, extending from 1928 to 1931, in which C. L. Cooper, Lloyd Henbest, C. B. Read, and David White participated with the writer at different times, was rewarded by the discovery near Prairie Grove, Arkansas, of a large flora[32] in the Wedington sandstone member of the Fayetteville shale (Mississippian) and also by the discovery of a small flora from the Hale sandstone, the basal unit of the Morrow group (Pennsylvanian) in Fayetteville, Arkansas (Fig. 4). The collection of these floras seemed essential in order that the floras from the Stanley and Jackfork might be compared with them. Not only does the southern Ozark region lie near the Ouachita region, but it reveals a sequence of Carboniferous rocks whose assignment to the Mississippian and Pennsylvanian has been based on abundant invertebrate fossils occurring throughout the sequence. In addition the "coal-bearing shale," a member in the lower part of the Bloyd shale, the top unit of the Morrow group, yielded many years ago one of the few very large collections of plants thus far obtained from the Carboniferous in the United States.

### FOSSIL PLANT EVIDENCE INTERPRETED BY DAVID WHITE

The age significance of the floras from the Jackfork and Stanley formations and their comparisons with floras from the Wedington sandstone member of the Fayetteville shale and from the Morrow group are discussed by David White[33] in his paper which was presented by title at the Dallas meeting of The American Association of Petroleum Geologists and which is printed in this *Bulletin*.

The flora from the Jackfork has been obtained from different

[32] Described by David White in manuscript report.

[33] David White, "The Age of the Jackfork and Stanley Formations of the Ouachita Geosyncline as Indicated by Plants," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), pp. 1010–17.

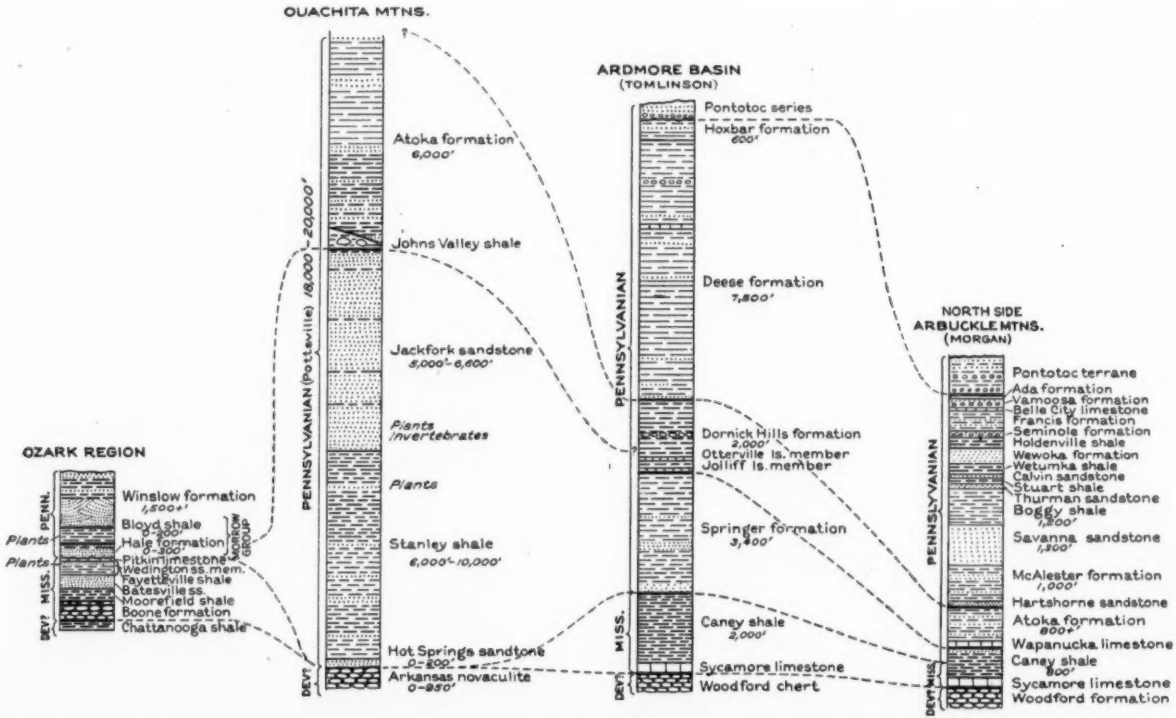


FIG. 4.—Series of columnar sections showing suggested correlation of Pennsylvanian rocks of Ouachita Mountains with rocks of this age in Ozark region, Ardmore basin, and north side of Arbuckle Mountains.

horizons in the formation, but most of the material was collected from the lower part of the formation in a canyon-like valley known as Devils Hollow, 3 miles west-northwest of Talihina, Oklahoma. Nearly all the fossil plants from the Stanley shale have been obtained from the upper part of the shale; the greatest number of forms is represented in a collection from a shale bed at the south side of the highway viaduct over the Whitley cut on the Kansas City Southern Railroad, 2.5 miles by road south of Gillham, Arkansas.

The Stanley and Jackfork floras are stated by White to be younger than the Wedington sandstone member of the Fayetteville shale and to be older than the flora of the "coal-bearing shale," a thin member in the lower part of the Bloyd shale of the Morrow group (Fig. 4). The flora of the coal-bearing shale is regarded by him as middle Pottsville in age and certainly not older than middle Pottsville. The plant-bearing portions of the Stanley and Jackfork are referred by him to the "early Pottsville or pre-'coal-bearing shale' time, specifically the lower Pottsville," which embraces the Lookout sandstone of Georgia and Tennessee, the Lee formation of Virginia, the Pocahontas formation and Raleigh sandstone of West Virginia, and the Lower Lykens coal group of the Southern Anthracite field in Pennsylvania.

Available plant evidence, according to White, seems insufficient for warranting more than a provisional assignment of the pre-"coal-bearing shale" portion of the Morrow group to the lower Pottsville. The stem casts and impressions of *Lepidodendron* from the Hale sandstone, the basal unit of the Morrow group, are stated by White to point toward the complete inclusion of the Morrow in the Pennsylvanian, but he says these plant remains are not of a nature to permit a more restricted reference of the Hale. Available plant evidence is, therefore, inconclusive regarding the correlation of the Stanley and Jackfork formations with the lower portion of the Morrow group of the Ozark region.

### INVERTEBRATE FOSSILS FROM STANLEY AND JACKFORK FORMATIONS

Invertebrate fossils are extremely meager in the Stanley and Jackfork formations and perhaps not more than half a dozen collections have been obtained.

A few invertebrate fossils have been found in the Stanley shale by Honess in McCurtain County, Oklahoma. The following statement from his report gives the opinion of Charles Schuchert concerning them.[34]

[34] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull.* 32 (1923), pp. 177–78.

It seems to me fairly certain that these specimens cannot be other than Mississippian or Pennsylvanian. As you got an undoubted *Lepidodendron* even beneath lots 943 and 944, and as the specimen appears to me like a Pennsylvanian form, it seems that the whole of the Stanley and Jackfork may be Pennsylvanian in age rather than Mississippian. The marine fossils do not indicate anything to the contrary.

The same fossils as those submitted to Schuchert were also submitted to E. O. Ulrich, who reports in part:[35]

The invertebrate part of the evidence by itself would not be conclusive either way. The trend of the evidence is toward the Pennsylvanian rather than the Mississippian (either early or late). Again there is nothing in the collection that may be justly cited as definitely opposed to correlation of the Stanley with lower Pottsville or basal Morrow, which conclusion I reached in my "Revision" mainly on physical and diastrophic considerations.

The fossils observed by me in the Jackfork seemed decidedly corroborative of my convictions respecting the post-Chester age of the Stanley. So far as I can see, your new evidence leaves the problem just about where I left it in 1911—that is, with the probabilities favoring assignment of the Stanley to the earlier Pennsylvanian.

The largest collection of invertebrate fossils obtained by the writer from the Jackfork sandstone was procured from a horizon in the sandstone a few hundred feet above its base, in a quarry, now abandoned, just northwest of Pulaski Station on the Chicago, Rock Island, and Pacific Railroad, 2 miles northwest of Little Rock, Arkansas. The quarry is on the right bank of Arkansas River and is opposite Big Rock Mountain, on which Fort Logan H. Roots stands. The locality was first visited by the writer in 1918, in company with L. W. Stephenson, and the presence of fossils was then learned, but because the writer did not then know the sandstone at the locality is Jackfork, and because his time was occupied with urgent duties in connection with the World War, a collection was not then obtained. A second visit was made in 1927 in company with G. C. Branner, but no fossils were found. A third visit was made in 1931 in company with Harlton, and a collection concerning which Girty has given a statement, quoted below, was obtained. The collection was, however, not as satisfactory as could be wished and with the hope of finding better material a fourth visit was made in 1932 in company with R. C. Moore. This visit, however, contributed no material of value.

Girty's statement concerning the Jackfork fauna from the Pulaski (Arkansas) locality follows.

Your collection made near Little Rock, Arkansas, is the only significant collection of invertebrate fossils from the Jackfork sandstone that I have

[35] *Ibid.*

seen, or that, perhaps, has yet been made. Consequently I have examined it with much interest and have spared no effort in studying it. As was to be expected in a formation which in most places contains no invertebrate fossils at all, the fossils from the Little Rock locality are mostly fragmentary and otherwise in a poor state of preservation. In identifying this material I have gone to what I regard as the extreme limit of prudence, and yet, as you will observe, few forms have received more than a generic designation and none has received a positive specific designation. The following list shows the forms that I have been able to distinguish.

FOSSILS FROM JACKFORK SANDSTONE, FROM QUARRY NEAR PULASKI, ARKANSAS

*Echinocrinus* sp.
*Fenestella* aff. *lenax*
*Crania*? sp.
*Orbiculoidea*? sp.
*Rhipidomella*? sp.
*Orthotetes*? sp.
*Chonetes* aff. *Illinoisensis*
*Chonetes arkansanus*?
*Chonetes* sp.
*Productus* aff. *ovatus*
*Productus* sp.
*Pustula* sp.
*Spirifer* aff. *keokuk*
*Spiriferina kentuckyensis*?
*Composita*? sp.
*Hustedia mormoni*?
*Leda* aff. *arata*
*Anthraconeilo*? sp.
*Myalina*? sp.
*Astartella*? sp.
*Laevidentalium*? sp.
*Pleurotomaria* sp. 1
*Pleurotomaria* sp. 2
*Naticopsis* aff. *carleyana*
*Schizostoma*? sp.
*Orthoceras*? sp.
*Griffithides* sp.
*Sansabella*? sp.

The evidence of the invertebrate fossils, quite apart from the evidence along other lines, appears to indicate that the age of the outcrop near Little Rock is Pennsylvanian and more particularly Pottsville. This opinion rests on the following considerations. We have, in Arkansas, several Mississippian formations which not only contain the most distinctive Chester invertebrates, but contain them in such profusion that no collection, however small, but can be definitely recognized as of that age. The fauna here under consideration, however, does not show any definite relationship to those Chester faunas or to any Mississippian faunas elsewhere found. On the contrary, such relations as are definitely indicated ally it with faunas of Pennsylvanian, especially with faunas of Pottsville age. It is true that a few forms are compared in the list with Mississippian species, but this means nothing, for species of closely similar character occur also in the Pennsylvanian. For instance, a species of *Productus* is compared with the Mississippian *P. ovatus* rather than with the Pennsylvanian *P. cora* because the specimen was small, on that account recalling *P. ovatus*, and because it did not show, though it may have possessed, the characters that distinguish *P. cora*.

On the opposing side, *Chonetes arkansanus*? is probably identical with a Morrow species; *Hustedia mormoni*? is fairly indicative of Pennsylvanian time; *Leda* aff. *arata* is very similar to an undescribed species of Pottsville age, and I believe identical with it; *Astartella*? sp. is probably identical with another undescribed species from the Morrow formation; and the small gastropod cited as *Naticopsis* aff. *carleyana* can probably be matched by specimens from the Morrow. The most significant of these is *Leda* aff. *arata*, which is a rather peculiar species and which, so far as its characters are shown, is identical with a Pottsville species.

As to the age of this fauna in the Pottsville, it would probably be unwise to say anything definite. The Morrow formation, on the paleobotanical evidence, is middle Pottsville according to last advices. I am not sure, however, that this fauna from the Jackfork sandstone is as young as the Morrow, although it may be. The noteworthy species cited as *Leda* aff. *arata* does not occur in the typical Morrow fauna, but it does occur in several other faunas of Pottsville age and probably the less distinctive forms occur in those same faunas. I seem to recognize your Jackfork fauna in a collection 300 feet more or less below the main limestone of the Wapanucka near Natural Arch in the McAlester quadrangle (station 3883), in collections from some thin limestone sheets included in shale that Mr. Taff regarded as upper Caney also in the McAlester quadrangle (station 3880), in some collections from yellowish limestone enclosed in green shale below the Wapanucka limestone near Bromide in the Atoka quadrangle (station 4046a. The Wapanucka limestone here is oölitic and thick enough to be quarried), and lastly in a number of collections in the Otterville limestone of the Ardmore quadrangle.

Some of the afore-mentioned faunas (stations 3883, 3880, and 4046a) that are similar to those of the Jackfork are stated by Girty to have been obtained from beds underneath the Wapanucka limestone and all of them, therefore, appear to come from the Springer formation of the Ouachita region or from equivalent beds. The Otterville limestone, which, as already mentioned, contains faunas comparable with the Jackfork, is described by C. W. Tomlinson[36] as a member in the lower part of the Dornick Hills formation, which overlies the Springer formation in the Ardmore basin. The Otterville is generally regarded as being equivalent to a portion of the Wapanucka limestone (Fig. 4).

### MICROFOSSIL EVIDENCE INTERPRETED BY B. H. HARLTON

Through the efforts of Powers and Harlton beginning in 1927, a large microfauna of Pennsylvanian age from the Johns Valley shale has been obtained and was described by Harlton in 1933.[37] Microfossils flourished in the Johns Valley sea and, although they predominate over other types of fossils, many hundreds of shale samples were collected from which Harlton obtained the fauna described by him. On the basis of these fossils he correlates the Johns Valley shale with the lower portion of the Dornick Hills formation of Tomlinson in the Ardmore basin of Oklahoma, the Wapanucka limestone of southern Oklahoma, and the Morrow group of the Ozarks.

Also, in a paper in this *Bulletin* (pages 1018–49) he lists microfossils

[36] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929).

[37] B. H. Harlton, "Micropaleontology of the Pennsylvanian Johns Valley Shale of the Ouachita Mountains, Oklahoma, and Its Relationship to the Mississippian Caney Shale," *Jour. Pal.*, Vol. 7, No. 1 (March, 1933), pp. 3–29.

of Pennsylvanian age from many different horizons in the Stanley shale and Jackfork sandstone.

## JOHNS VALLEY SHALE AND ITS ERRATIC BOULDERS

### GENERAL STATEMENT

The Johns Valley shale and the erratic boulders that it contains present puzzling problems in the paleogeography of the Ouachita and adjoining regions, and they also suggest interesting speculations about the structural history of the Ouachita Mountains. The problems connected with the boulders, especially those relating to their origin, may never be completely solved. It is not the writer's purpose to describe in detail the Johns Valley shale and its boulder deposits in this paper, but rather to summarize the information he has obtained from field studies during visits to the region in the last 10 years, and to present tentative conclusions that seem to be warranted by the available evidence. In addition, the contributions of other workers have been utilized and references to them are made at different places in the text.

The boulder deposits have been described or discussed briefly by Taff,[38] J. B. Woodworth,[39] Samuel Weidman,[40] Tomlinson,[41] Charles Schuchert,[42] Harlton,[43] and the writer,[44] and have been more fully

[38] J. A. Taff, "Some Erratic Boulders in Middle Carboniferous Shale in Indian Territory," abstract, *Science*, new ser., Vol. 21 (1905), p. 225.
———, "Ice-Borne Boulder Deposits in Mid-Carboniferous Marine Shales," abstract, *ibid.*, Vol. 29 (1909), p. 637.
*Ibid.*, *Bull. Geol. Soc. Amer.*, Vol. 20 (1910), pp. 701–02.

[39] J. B. Woodworth, "Boulder Beds of the Caney Shale at Talihina, Oklahoma," *Bull. Geol. Soc. Amer.*, Vol. 23 (1912), pp. 457–62.
*Ibid.*, abstract, *Science*, new ser., Vol. 35 (1912), p. 319.

[40] Samuel Weidman, "Was There Pennsylvanian-Permian Glaciation in the Arbuckle and Wichita Mountains of Oklahoma?" *Jour. Geol.*, Vol. 31, No. 6 (September–October, 1923), pp. 487–88.

[41] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 25–27.

[42] Charles Schuchert, "Review of the Late Paleozoic Formations and Faunas, with Special Reference to the Ice-Age of Middle Permian Time," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 837–38.

[43] B. H. Harlton, "Micropaleontology of the Pennsylvanian Johns Valley Shale of the Ouachita Mountains, Oklahoma, and Its Relationship to the Mississippian Caney Shale," *Jour. Pal.*, Vol. 7, No. 1 (March, 1933), pp. 5–7.

[44] H. D. Miser in H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 44* (1927), footnote on pp. 22 and 23.
H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 50* (1929), pp. 27–30.
———, "Oklahoma Structural Salient of the Ouachita Mountains," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), p. 138.
———, *Jour. Washington Acad. Sci.*, Vol. 23, No. 2 (February 15, 1933), p. 112.

described by Ulrich,[45] Powers,[46] W. A. J. M. van Waterschoot van der Gracht,[47] E. E. L. Dixon,[48] and W. B. Kramer.[49]

### DIFFERENT HYPOTHESES ON ORIGIN OF BOULDERS

In Ulrich's 1927 paper, as well as all earlier papers on the Ouachita region, the hypothesis of ice rafting as a means of transporting the erratic boulders was held. The discovery late in 1926 by Sidney Powers and R. A. Birk of gigantic masses of Ordovician limestone ranging up to 370 feet in length—many times larger than had been found earlier by Taff and Ulrich—had the immediate effect of leading many geologists, including Sidney Paige,[50] Powers, and the writer, to consider the possibilities of thrust faulting, but because of apparently fatal objections to the thrusting theory, Powers and the writer held tentatively to the ice-rafting theory. Van der Gracht has advocated a hypothesis of overthrust faulting from the south to explain the origin of the boulders. Harlton holds to the overthrust theory, but believes that mud flows aided in the distribution of the boulders. On the other hand, Dixon, followed by Kramer, suggests the boulders reached their present position by means of submarine land slips. These several hypotheses are discussed by the writer at places in the succeeding pages in which the boulder deposits are described.

[45] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), pp. 352, 360–61.
———, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

[46] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 1031–72.

[47] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *K. Aked. Wetensch. Amsterdam Vers., Afd. Natuurk.*, Deel 27, No. 3 (1931), pp. 50–62.
*Ibid.*, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931).
———, "The Pre-Carboniferous Exotic Boulders in the So-Called 'Caney' Shale in the Northwestern Front of the Ouachita Mountains of Oklahoma," *Jour. Geol.*, Vol. 39, No. 8 (November–December, 1931), pp. 697–714.
*Ibid.*, review by R. H. Dott, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 5 (May 1932), pp. 495–97.

[48] E. E. L. Dixon, "The Ouachita Basin of Oklahoma vis-a-vis the Craven Lowlands of Yorkshire," *Geol. Mag.*, Vol. 68, No. 806 (August, 1931), pp. 337–44.

[49] W. B. Kramer, "Boulders from Bengalia," *Jour. Geol.*, Vol. 41, No. 6, (August–September, 1933), pp. 590–621.
*Ibid.*, review by B. H. Harlton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1538–39.

[50] Sidney Paige, oral discussion (unpublished) at Tulsa meeting of the Amer. Assoc. Petrol. Geol. of paper by E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

### DISTRIBUTION OF JOHNS VALLEY SHALE AND THE BOULDERS

The Johns Valley shale is exposed in the portion of the Ouachita Mountains southeast of the Ti Valley fault (Fig. 1). As stated earlier, the sequence there includes the following recognized units, the oldest being named first: Hot Springs sandstone, Stanley shale, Jackfork sandstone, Johns Valley shale, and Atoka formation. Apparently the distribution of the boulders is co-extensive with that of the Johns Valley shale, which forms narrow bands of exposure lying on the northwest side of the Ouachita region. The area containing the exposures of the Johns Valley shale is 17 miles in width and 125 miles in length. It extends from the west end of the Ouachita Mountains near Atoka, Oklahoma, eastward to Boles, Arkansas.

All the belts of outcrop of the Johns Valley shale are in a mountainous region and they occur either in valleys or on mountainsides. Because of the forest cover and a thick soil and talus cover there are few actual exposures showing boulders in place in their shale matrix. Moreover, most of the exposures are relatively small. Thousands of boulders or fragments of residual chert derived from the boulders can, however, be found in the talus material in all the portions of the region that contain no actual exposures of the shale matrix.

### POSITION OF BOULDERS IN THE JOHNS VALLEY SHALE

The boulders do not occur in ordinary gravel or boulder beds, such as coarse conglomerate, but are irregularly scattered through a marine shale like "plums in a pudding." Most of the boulders are thus separated from one another by shale, but there are numerous occurrences where boulders are found in nests or pockets in which the boulders touch one another or nearly so. These nests or pockets may consist of boulders surrounded by cobbles and pebbles or may simply consist of cobbles and pebbles in a shale matrix. The boulders are not oriented with their longer dimensions parallel with the bedding and their distribution according to size does not bear any relation to bedding.

The boulders do not all lie in the same stratigraphic position in the Johns Valley shale. The relatively few exposures of boulder-bearing shale indicate the presence of two different boulder horizons —one is in the lower 50–100 feet of the shale, and the other, about 100 feet thick, forms the top bed of the Johns Valley shale. Between the two horizons there is much shale that is free from boulders. This shale, however, contains a thin calcareous or pebbly sandstone. The boulders in Johns Valley, the type locality of the Johns Valley shale, and also the boulders at numerous other places are found in the lower

part of the shale (Figs. 1 and 5). The upper boulder-bearing bed is best exposed in a creek bank at Lamberson Spur, and in a deep cut at Compton Spur, both of which are on the Frisco Railroad several miles north of Talihina, Oklahoma.

### CHARACTER AND AGES OF LIMESTONE ERRATICS

The limestone erratics in the Johns Valley shale include many different kinds of limestone and with them there are relatively few chert and sandstone fragments. Most of the chert, however, forms a portion of the unweathered limestone masses.

Some limestone boulders show on their surfaces small channels that are now filled with shale. Their forms, including their rounded walls, indicate that solution formed the channels before the boulders were transported and deposited in the Johns Valley shale. Possibly, this solution took place on a land area from which the boulders were derived. Many erratic pebbles widely scattered through shale exposures are well rounded and resemble in every feature water-worn pebbles. Their great number and shape suggest that such material was derived from beach or stream gravel. All the limestone blocks and pebbles that are not actually embedded in shale have, however, been greatly modified in form by solution and fracturing during exposure to recent weathering agents.

Many limestone blocks show straight and crooked grooves and gouges an inch or less in width but many inches in length. The material formerly occupying the grooves has been pushed aside as if it had once been plastic; much of it forms ridges alongside the grooves. Some grooves are associated with fractures and their relations are such as to indicate that the grooves and the fractures were formed at the same time as the result of the rubbing of one boulder against another. Also other boulders have been cracked and the resulting fragments have been rotated. The writer believes the fracturing and the grooving of the boulders took place during intense deformation of the shale. This deformation was coincident with the folding and faulting of the rocks of the Ouachita Mountains, presumably in middle or late Pennsylvanian time.

The most common size of the limestone erratics is that of pebbles and cobbles; masses measuring 10 feet in their largest dimension may be seen occasionally; a few blocks, some 30 feet across, are known; still fewer blocks 50–60 feet long are known; and four blocks of great size (Fig. 5) are known to the writer. The localities and exposed dimensions of all the limestone blocks known to the writer that measure 40 feet or more in length are here listed.

LARGE LIMESTONE BOULDERS IN JOHNS VALLEY SHALE

*Brashears boulder.*—Dips steeply east; length of exposure 370 feet; exposed width (thickness) 50 feet; SE. ¼, Sec. 10, T. 1 S., R. 16 E., Johns Valley, Oklahoma

*Baskett boulder No. 1.*—Dips steeply; strikes north; poorly exposed for length of 220 feet; 0.25 mile north of Baskett ranch house; Sec. 4, T. 1 S., R. 16 E., Johns Valley, Oklahoma

*Baskett boulder No. 2.*—Dips steeply east; poor exposures in area 40 by 150 feet; 0.5 mile north of Baskett ranch house; NW. ¼, Sec. 4, T. 1 S., R. 16 E., Johns Valley, Oklahoma. This boulder is the one about which Powers* cites C. W. Miller as authority for the exposed measurements of 550 feet by 65 feet; these measurements were not indicated to the writer at the time of the writer's visit, because the exposures are poor and discontinuous

*Section Five boulder.*—Dips east at low angle parallel with slope; exposed in area 110 by 195 feet; 0.75 mile west of Baskett ranch house; SE. ¼, Sec. 5, T. 1 S., R. 16 E., Johns Valley, Oklahoma

*A limestone boulder.*—Exposure 60 by 30 feet; Sec. 32, T. 4 N., R. 20 E.; 10 miles west of Talihina, Oklahoma; observed by J. A. Taff, August 26, 1908; has not been visited by the writer

*Several limestone boulders.*—40–55 feet in length near Boles, Arkansas

* Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. Amer.*, Vol. 39 1928), p. 1043.

Each boulder that contains fossils has a distinctive fauna. The many fossils that are represented by collections from boulders at numerous localities have been demonstrated by Ulrich, Josiah Bridge, C. B. Read, and Girty to range in age from Ordovician to early Pennsylvanian. The faunas are also the same as, or similar to, the faunas of the exposed rocks of the Arbuckle Mountains, the Ti Valley-Choctaw belt, and the Ozark region.

The four large boulders in Johns Valley, in the foregoing list, are faunally and lithologically like a portion of the Bromide formation of Ulrich in the Arbuckle Mountains. They contain the fossil sponge *Ischadites*, as do certain beds of the Bromide.[51]

In 1927 Ulrich[52] listed and described the faunas from numerous boulders in Oklahoma. He determined a total of about 189 species. The named geologic units with which the boulders and their faunas are comparable or from which the boulders may have been derived were determined as follows by Ulrich:

Wapanucka limestone (Pennsylvanian)
Caney shale (Mississippian)
Sycamore limestone (Mississippian)
Pinetop chert (Middle Devonian; formerly designated by Ulrich as Brushy Creek chert)
Chimneyhill formation (Silurian)
Sylvan shale? (Upper Ordovician)
Fernvale limestone (Upper Ordovician)
Chazyan, Black River, and Trenton fossils (Ordovician) from Viola and Simpson formations as described by J. A. Taff in *U.S. Geol. Survey Prof. Paper 31.*
Arbuckle limestone (Ordovician)

[51] C. E. Decker and C. A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (1931), pp. 40–49.

[52] E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

Josiah Bridge has supplied the following statement concerning 24 collections of fossils obtained by the writer from erratic boulders near Boles, Arkansas. Each collection comes from a single boulder. Ulrich has seen the collections and agrees with the report.

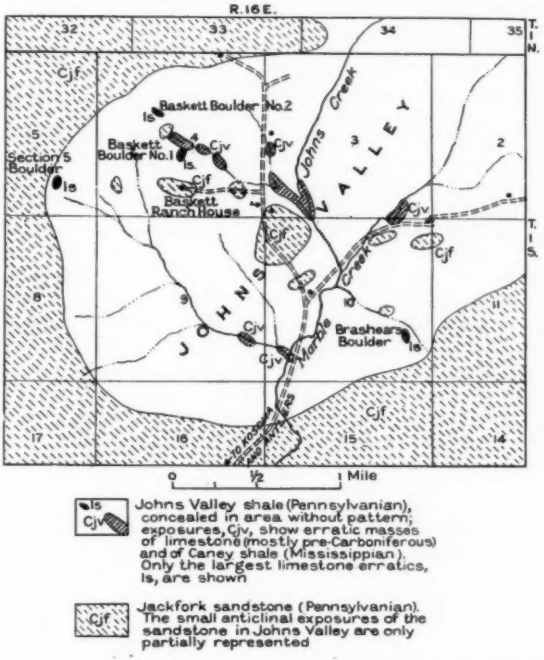


FIG. 5.—Geologic map of southern portion of Johns Valley, Oklahoma, showing all known exposures of Johns Valley shale in valley and showing location of large limestone boulders. Map modified after C. W. Miller.

I find four epochs represented—upper Beekmantown, lower Trenton, Richmond, and Mississippian?

The Beekmantown is represented by 11 lots. The matrix of each lot is rusty porous chert. Most of the identifications are merely generic, for the preservation is very poor and in many cases the individuals belong to undescribed species. The following genera have been recognized: Gastropoda—*Orospira, Euconia, Ophileta, Helicotoma, Hormotoma, Coelocaulus;* Crustacea—*Bolbocephalus* (trilobite) and *Eopterica* (phyllopod). The entire assemblage is highly characteristic of the Cotter dolomite of northern Arkansas and southern Missouri, and the boulders containing this fauna are definitely referred to it.

Nine collections may be referred to various horizons in and near the base

of the Trenton. Three of these lots are characterized by an abundance of the pelecypod *Vanuxemia* cf. *gibbosa* and appear to represent a single horizon. This *Vanuxemia* zone is present near the base of the Viola limestone on the north side of the Arbuckle Mountains. It also occurs in central Tennessee and in Minnesota and Wisconsin, but is unknown in the Missouri sections and also in the sections on the south side of the Arbuckle Mountains.

A second suite consisting of two collections appears to represent a zone which is either late Black River or early Trenton in age. The rock is a blue, rough-weathering, hard-looking limestone which greatly resembles certain beds in the upper part of the Bromide formation of Ulrich, or basal Viola formations. Fossils are abundant, but very poor. Gastropods are represented by forms referable to *Trochonema*, *Helicotoma?* and *Hormotoma*, while the Bryozoans are represented by *Solenopora* and other forms.

A third suite, containing three collections, also belongs somewhere in the Trenton. It is characterized by an abundance of a certain species of *Dalmanella*—a form which, according to G. A. Cooper, is a typical Trenton form.

A single collection of sandy boulders, evidently a decalcified arenaceous limestone, contains numerous specimens of the gastropod *Maclurea*. This collection may be of Chazy or Black River age, but is probably Trenton.

The Fernvale horizon is represented by a single large collection from a gray coarsely crystalline limestone. The lithology is characteristic of the Fernvale formation, both in the Ozarks and the Arbuckles. The most characteristic fossil is the brachiopod *Cliftonia ulrichi*. This species was originally described from beds of Richmond age in Minnesota, but Ulrich and I have found it near the base of the beds of Fernvale age on the north side of the Arbuckle Mountains. I have not yet found it in collections from Missouri and Arkansas, though it may be present.

The two remaining collections are too indefinite for accurate determination. Each one consists of a single fragment of hard, white chert with a single fossil. On lithologic grounds I would class both as Boone. One of the fossils is a coral—probably *Amplexus* cf. *fragilis*—a common early Mississippian form.

A silicified log, 1.5 feet long and 1 foot in diameter, from the Johns Valley shale on Mayes Branch near Boles, Arkansas, has been identified by Read as belonging to the genus *Callixylon*. The form and its state of preservation lead him to conclude that it has been derived from the Woodford chert. Such fossil wood is also found in the upper division of the Arkansas novaculite, but it is more silicified and lighter in color than the wood from the Woodford chert.

A ferruginous shaly limestone mass, 2 feet across, that appears to be an erratic, was found on the surface at a locality known as the Blowout, in the southwest corner of Sec. 5, T. 1 N., R. 28 W., 2.5 miles east-southeast of Boles, Arkansas. The following list of fossils has been identified by Girty in a collection from the boulder.

*Schizophoria?* sp.
*Orthotetes?* sp.
*Pleurophorus* sp.
*Astartella* sp.

*Spirifer* aff. *rockymontanus*
*Nucula* sev. sp.
*Leda* sp.
*Solenomya? sharonensis*
*Aviculipecten*
*Pleurotomaria* sp.
*Schizostoma?* sp.
*Gastrioceras nolinense?*
*Griffithides* sp.

Girty states that this collection may provisionally be regarded as belonging in point of geologic time with the Springer formation, the Wapanucka limestone, and the Morrow group.

ERRATIC MASSES OF CANEY SHALE (MISSISSIPPIAN)

Erratic masses of Caney shale of Mississippian age are doubtless numerous in the Johns Valley shale, but there are very few good exposures of the Caney shale masses. The exposures reveal a shale that can be matched in every lithologic feature with the Caney shale of the Ti Valley-Choctaw belt and the Arbuckle Mountain region. The shale is hard and platy; it contains concretions of black limestone reaching many feet in their longest dimensions; and it contains numerous phosphatic concretions measuring as much as 1 inch in diameter and having a spherical or nearly spherical form. Invertebrate fossils that form a part of the Caney fauna as described by Girty[53] are common in the limestone concretions, in the phosphate concretions, and along the partings of the shale. The character of the shale and the arrangement of the fossils in it clearly show that the fossils are the remains of animals that lived, died, and were buried in the shale in which they are now found.

Five years ago (1929) the writer formulated and tested in the field a hypothesis that masses of shale of Mississippian age may have reached their position above the Jackfork sandstone in the same manner as the erratic limestone blocks—perhaps by thrust faulting or ice rafting. C. L. Cooper and John Fitts joined the writer in visiting at that time all the then known exposures of shale of Mississippian age on top of the Jackfork sandstone. The largest of these exposures, which are in Johns Valley and in Cooper Hollow, Oklahoma, were found to measure as much as 500 feet in length. In 1931 an exposure, approximately 600 feet in length, was studied by the writer on Countis Branch near Boles, Arkansas. The exposures are, however, so large and so incomplete that there seemed to be no justification in reaching a definite decision about the erratic nature of the shale until the evidence now in hand has become available. The writer's present conclusions, which are not simply based on the character of the exposures but also on the accordant evidence of the fossil plants,

[53] G. H. Girty, "The Fauna of the Caney Shale of Oklahoma," *U.S. Geol. Survey Bull. 377* (1909).

the macro-fossils, and the micro-fossils, for a Pennsylvanian age for the subjacent Stanley and Jackfork formations, are (1) that the shale of Mississippian age represents erratic masses and (2) that, therefore, the Mississippian shale does not constitute a unit overlying the Jackfork sandstone in a normal stratigraphic sequence (Fig. 3 B).

The great size of these shale masses, as well as the large dimensions of some of the limestone blocks, seem to make it necessary to consider other agencies than ice rafting to explain the origin of at least a major portion of the erratic material in the Johns Valley shale.

### CHARACTER AND AGE OF BEDS INCLOSING BOULDERS

The shale in which the boulders are inclosed is black and much of it is blocky and free from laminations and platy partings but much of it, as well as the shale that is free from boulders, is platy. It is softer than the shale composing the erratic masses of the Caney shale. Clay ironstone concretions are common in the boulder-bearing shale and also in the shale free from boulders. The clay ironstone concretions lie for the most part parallel with the bedding of the shale, but the pebbles and boulders lie in the shale with no general orientation of their longer dimensions.

Some thin, finely laminated sandstone is exposed at places. It is, however, present in the portions of the Johns Valley shale that are free from erratics.

A calcareous sandstone bed that is in places conglomeratic contains a few poorly preserved macro-fossils. It underlies the upper boulder-bearing bed, as revealed in Compton Cut and at Lamberson Spur, Oklahoma. In a collection obtained by the writer from Crompton Cut the following forms have been identified by Girty.

Crinoid stems
*Lingula* aff. *Carbonaria*
*Orbiculoidea*
*Chonetes* sp.
*Chonetes*? sp.
*Rhipidomella* sp.
*Nucula*? sp.
*Aviculipecten* sp.
*Paraparchites* sp.
*Lonchodus*? sp.

In two collections obtained by the writer from Lamberson Spur, the following forms have been identified by Girty.

Lot 7231

*Lingula* aff. *Carbonaria*
*Orbiculoidea* sp.
*Orthotetes* (*Derbya*?) sp.
*Chonetes* sp.
*Productus* fragments
*Productus* aff. *cora*
*Pustula* aff. *punctata*
*Rhynchopora* sp.
*Spirifer* aff. *rockymontanus*
*Griffithides* sp.
*Ostracoda* indet.

Lot 7231a

*Pustula*? sp.
*Euomphalus*? sp.
*Conocardium* sp.

Concerning these collections, Girty says the evidence indicates that they may provisionally be regarded as belonging in point of geologic time with the Springer formation Wapanucka limestone, and the Morrow group.

The boulder-bearing Johns Valley shale forms a portion of a thick sequence of rocks that have been much faulted and greatly folded. This shale lying between two sandstone-bearing units, the Jackfork sandstone, below, and the Atoka formation, above, has been crumpled and faulted. The best exposure revealing these features is in Compton Cut. There, as well as elsewhere, the thin sandstone beds in the shale have been twisted and have been broken into slickensided slabs, many of which have been pulled apart and become separated during the deformation.

### EXOTIC NATURE OF BOULDERS

The lithologic character, as well as the faunas, of all the erratics—limestone, chert, sandstone, and shale—thus far observed by the writer and other geologists, indicate clearly that the erratic masses are exotic, that is, none of them has been derived from any of the formations exposed in the part of the Ouachita region south of the Ti Valley fault. The boulders can be matched lithologically, as well as faunally, with the Arbuckle Mountain facies as exposed in the Choctaw-Ti Valley belt and in the Arbuckle Mountains, and with some rocks exposed in the Ozark region.

### STRUCTURAL RELATIONS OF BOULDER DEPOSITS

The arcuate belt of country containing the exposures of the boulder-bearing Johns Valley shale follows the frontal margin of the Oklahoma structural salient for a distance of 125 miles (Fig. 1). The belt is 17 miles in width and lies entirely south of the Ti Valley fault, one of the faults in the frontal portion of the salient. Along this fault two different sequences or facies of rocks, the Ouachita Mountain sequence and the Arbuckle Mountain sequence, are brought together. The frontal margin of the salient containing the boulder deposits appears to have been thrust in a northwesterly direction a distance of 20 miles or more over rocks of the Arbuckle Mountain sequence. The salient is characterized by long, roughly concentric overthrust faults which bound northwestwardly thrust sheets (Fig. 2).

The boulder-bearing Johns Valley shale is, therefore, exposed in a region whose rocks have been greatly deformed not only by folding but also by overthrust faulting. Available evidence, however, indicates that the boulder deposits lie in a normal stratigraphic sequence;

therefore they are not remnants of overthrust sheets, and they are not fault breccia. All observations made thus far by geologists are in accord that all the known erratic boulder deposits of the Ouachita Mountains lie within the Johns Valley shale. Also no boulder deposits are found along faults except in the places where the Johns Valley shale lies in its normal stratigraphic position next to a fault.

It is conceivable, as has been stated by Powers,[54] that a slice of the Arbuckle Mountain sequence may have been thrust from the north upon Jackfork sandstone in Johns Valley time. Such an overthrust sheet may have provided the blocks that are now embedded as boulders in the Johns Valley shale. There are, however, no visible remnants of such a thrust sheet; it may have been eroded away completely, it may now be concealed by the Atoka formation, or it may have been overridden by much later overthrusts, from the southeast. Surely extensive erosion to remove a thrust sheet of limestone in pre-Atoka time would have spread thick beds of limestone conglomerate in the Atoka in many parts of the Ouachita region. As a matter of fact, very little conglomerate is revealed anywhere in the Atoka. All the conglomerate in the Atoka, like that well exposed at Stapp, Oklahoma, appears to be composed of material derived from the boulder-bearing Johns Valley shale, which everywhere lies immediately subjacent to the conglomerate. The conglomerate is composed of well rounded, well sorted, water-laid pebbles, cobbles, and boulders that are lithologically similar to the erratic boulders in the Johns Valley shale.

Postulated faults that would be required to overthrust from the south one sheet or more of pre-Carboniferous limestone from which to derive in some way the erratic boulders, would, it seems, have cut upward through and across the Stanley shale, Jackfork sandstone, and the older rocks of the Ouachita Mountain region. Also, there should be some areas of pre-Carboniferous limestone lying adjacent to, and cutting across, the Stanley shale and Jackfork sandstone and older rocks of the Ouachita region, but no such areas are revealed anywhere in the Ouachita Mountains, or in deep wells that have reached the Paleozoic rocks underneath the Cretaceous south of the Ouachita Mountains. It may, therefore, be stated that no evidence, found thus far, indicates that any of the boulder deposits are related in origin to the overthrust faults that characterize the Oklahoma structural salient; but there is, as previously stated, a parallelism between the distribution of the boulders and the frontal margin of the struc-

[54] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), p. 1046.

tural salient. The cause of this relation is discussed under the next heading.

HYPOTHESIS OF SUBMARINE LAND SLIPS FROM A LOCAL SOURCE

The distribution of the boulders and their character suggest to the writer, as they did to Powers,[55] that the boulders had a local source. From the discussion of the lithology and fossil content of the erratic boulders, given on the preceding pages, it is seen that many formations represented by the boulders are exposed only in the Arbuckle Mountains; others, including the Pinetop chert which is not exposed in the Arbuckle region, are found in the Ti Valley-Choctaw belt; and two others (the Cotter dolomite and Boone chert) are exposed only in the Ozark region. The boulders from the Cotter and Boone have been found only near Boles, Arkansas, at the east end of the boulder-bearing area. They, therefore, lie nearer the Ozark region than most of the boulder deposits farther west. Also, the boulders near Boles do not appear to include a large proportion of boulders like the rocks exposed in the Arbuckle Mountains. The only exposures of the Pinetop chert, which may have provided the chert boulders with Onondaga fossils, are within the Ti Valley-Choctaw belt. There is thus a general zonal distribution of erratic boulders from west to east in the belt containing the Johns Valley shale.

Erratic boulders of as great size as those in the Johns Valley shale did not, the writer believes, come from the Arbuckle Mountains or from the Ozark region. Several objections against such sources are: (1) no Pennsylvanian rocks exposed in or near the Arbuckle and Ozark regions contain erratic boulders comparable in size with any of the larger boulders in the Johns Valley shale; (2) the distances from the many boulder exposures to the Ozark and Arbuckle regions are great, reaching 100 miles; and (3) there appears to be no method of transporting erratics of large magnitude for such distances.

The writer's present conclusion accords with Powers' suggestion that they came from a mountainous uplift in southeastern Oklahoma over which the western end of the Ouachitas has been overthrust toward the northwest. The exposures of Caney shale and older rocks in the Ti Valley-Choctaw belt may represent partially revealed portions of this mountainous area. These exposures are chiefly in Ti Valley and near Bengal. The land area may thus be appropriately designated the Ti Valley-Bengal uplift.

E. E. L. Dixon,[56] who has carefully analyzed the Ouachita litera-

[55] Sidney Powers, *op. cit.*, pp. 1042–49.

[56] E. E. L. Dixon, "The Ouachita Basin of Oklahoma vis-a-vis the Craven Lowlands of Yorkshire," *Geol. Mag.*, Vol. 68, No. 806 (August, 1931), pp. 337–44.

ture in relation to the submarine land slips in Yorkshire, has added the further suggestions that "a long and high fault-scarp of a variety of Paleozoics, chiefly limestones of Arbuckle types" lay somewhere near the position of the Choctaw fault and that successive land slips from this scarp slid seaward over the black boulder-bearing mud that was being deposited at its foot on the south.

A hypothesis for a land area as postulated by Powers and for scarps from which there were submarine land slips seems to the writer to be worthy of serious consideration. In fact, all features of the boulders seem to support it, except perhaps the apparent great distance that some of the boulders would, according to this hypothesis, need to slide. From such a scarp most of the material would not have slid more than a few miles, but some masses like those in Johns Valley would, according to the hypothesis, have traveled seaward a distance of 20 miles or more from the uplift on the northwest. The postulated scarps were, perhaps, formed by faults—whether normal or thrust faults can not now be determined; but it seems they were probably thrust faults and if so, an overthrust sheet may have moved southward on top of the Jackfork sandstone in Johns Valley time. If such thrusting did take place, the distance that the boulders traveled from a fault scarp may not have exceeded a few miles. The possible southward thrusting may have taken place in response to a deepening of the northwest margin of the Ouachita geosynclinal belt in Oklahoma. Such thrusting would in reality be classed as underthrusting, provided the active movement, as believed by the writer, came from the southeast. This type of underthrusting is found in large areas in the Ouachita Mountains.

Although much of the erratic material may have been transported in submarine land slips, some of it, especially the smaller boulders, may have been rafted by shore ice. Furthermore, the movement of some of the erratic material may have started as slides on land.

That some of the exotic material was derived from land is shown by the well rounded nature of numerous erratic pebbles scattered through portions of the Johns Valley shale and also possibly by the solution channeling of some limestone masses before they were enclosed in the shale.

### BOULDER DEPOSITS AND SUBMARINE LAND SLIPS FOUND ELSEWHERE

Several recorded occurrences of boulder deposits and submarine land slips in other parts of the world are mentioned in the following paragraphs, because many of their features are comparable with those of the boulder deposits of the Johns Valley shale and also because they

seem to lend support to the interpretations here offered on the origin of the erratic boulders in that shale.

In the Marathon region, Texas, which is very similar in structure and rock facies to the Ouachita Mountains, boulder beds are found[57] in the Haymond formation of Pennsylvanian age. The boulders present a variety of sizes and ages. Some of them are of pre-Cambrian crystalline rocks. The larger blocks are of Devonian (?) novaculite as large as 50 feet across and fossiliferous Pennsylvanian limestone as large as 125 feet across. The boulders are embedded in massive arkosic mudstone, in which the large boulders are arranged in clusters. P. B. King, C. L. Baker, and E. H. Sellards, who have written about the region, are in accord that the boulder beds were formed by processes of transportation and deposition, and that they lie as true sedimentary layers in a normal stratigraphic succession of great thickness. Baker[58] offers the hypothesis of a glacial origin for the deposits. As stated by King,[59] "The large blocks are neither a tectonic breccia nor an originally continuous layer disrupted by faulting. . . . The deposit is in some wise related to the earliest phase of the Pennsylvanian mountain making in the Marathon region." In a similar way the boulder orogeny of the Ouachita region is related to the first of several deformational movements that affected the Pennsylvanian sequence of the Ouachita region. Also the boulder deposits near Marathon, Texas, are of Pottsville age, just as are the deposits in the Ouachita region of Oklahoma and Arkansas.

Near Settle, Yorkshire, deposits of erratic limestone boulders, described recently by E. E. L. Dixon and R. G. S. Hudson,[60] are embedded in the Bowland shales near the Craven faults. The deposits are explained as having resulted from "land slips down a muddy slope from a limestone cliff, probably a fault-scarp raised by the mid-Carboniferous earth-movement." A remarkable parallelism in the occurrence, character, and ages of the boulder deposits in the Bowland

[57] P. B. King, C. L. Baker, and E. H. Sellards, "Erratic Boulders of Large Size in the West Texas Carboniferous," abstract, *Bull. Geol. Soc. America*, Vol. 42, No. 1 (March, 1931), p. 200.

E. H. Sellards, "Erratics in the Pennsylvanian of Texas," *Univ. of Texas Bull. 3101* (1931), pp. 9–18.

P. B. King, "Large Boulders in the Haymond Formation of West Texas," *Bull. Geol. Soc. America*, abstract, Vol. 43, No. 1 (March, 1932), p. 148.

C. L. Baker, "Erratics and Arkoses in the Middle Pennsylvanian Haymond Formation of the Marathon Area, Trans-Pecos Texas," *Jour. Geol.*, Vol. 40, No. 7 (October–November, 1932), pp. 577–603.

[58] C. L. Baker, *op. cit.*

[59] P. B. King, *op. cit.*

[60] E. E. L. Dixon and R. G. S. Hudson, "A Mid-Carboniferous Boulder-Bed near Settle," *Geol. Mag.*, Vol. 68, No. 800 (February, 1931), pp. 81–92.

shale of Yorkshire and the Johns Valley shale of Oklahoma and Arkansas has been described by Dixon.[61] He calls attention to the occurrence of the boulders in Schuchert's Bendian in both of these widely separated areas.

The lower Paleozoic conglomerates at Quebec and Levis are explained in a recent paper by E. B. Bailey, L. W. Collet, and R. M. Field[62] as "submarine land slips in the early stages of the development and deformation of a geosyncline." Some of the reasons for interpreting them as land slips are

> (1) Through a succession of geological ages they repeatedly recur along a particular tectonic zone. (2) A large proportion of their boulders are penecontemporaneous. (3) Their internal arrangement is tumultuous and unbedded. (4) Some of their boulders are gigantic—certainly 60 feet long—and can be shown to have plowed into the underlying shale. (5) Their material has apparently moved to some extent *en masse*. (6) There is evidence of forcible injection of their scanty matrix into cracks.

Limestone breccia of Middle Ordovician age exposed along the coastal belt of western Newfoundland includes phenomenally large slabs, some of them as large as 600 feet across.[63] As stated by C. O. Dunbar,[63]

> It has recently been discovered that the breccia is associated with submarine thrust faulting, and the coarsest deposits represent submarine land slips along the noses of thrusts.

Submarine landslides are believed by F. P. Shepard[64] to have taken place along the continental slope off Georges Bank near the New England Coast. The continental slope has here much the appearance of a fault scarp and is subject to earthquakes. Canyons of great magnitude range up to 4,500 feet in depth and extend back from the front of the continental slope a distance of as much as 12 miles. According to Shepard the canyons are rock-walled and had a fluvial origin and from them landslides removed to the deep ocean floor the unconsolidated sediments that appear to have once filled the canyons.

[61] E. E. L. Dixon, "The Ouachita Basin of Oklahoma vis-a-vis the Craven Lowlands of Yorkshire," *Geol. Mag.*, Vol. 68, No. 806 (August, 1931), pp. 337–44.

[62] E. B. Bailey, L. W. Collet, and R. M. Field, "Paleozoic Submarine Land Slips near Quebec City," *Jour. Geol.*, Vol. 36, No. 7 (October-November, 1928), pp. 577–614.

[63] C. O. Dunbar, "Mid-Ordovician Thrust Faulting in Western Newfoundland," abstract, *Geol. Soc. Amer.*, "Preliminary List of Titles and Abstracts of Papers to be Offered at the Forty-Sixth Annual Meeting, Chicago, Illinois, December 28–30, 1933."
Charles Schuchert and C. O. Dunbar, "Stratigraphy of Western Newfoundland," *Geol. Soc. Amer. Memoir 1* (1934), pp. 73–86.

[64] F. P. Shepard, "Canyons off the New England Coast," *Amer. Jour. Sci.*, 5th ser., Vol. 27, No. 157 (January, 1934), pp. 24–36.

According to L. W. Collet[65] studies of sub-lacustrine land slips in Swiss lakes have shown that one land slip, precipitated by the driving of piles, carried away 20 houses and traveled for a kilometer.

Physiographic studies[66] of the effects following the Japanese earthquake of 1923 have shown, by means of soundings, a maximum subsidence at that time of 200 meters in certain places in the trench of the Sagami Bay and a maximum upheaval of 250 meters on a fault scarp following the northeast side of the trench. Also, "the northern flank of the submarine range . . . experienced a great slip 10 km. long, similar to a mountain slip on the land surface, filling the floor of the furrow with debris 230 m. in thickness."

### RELATION OF BOULDER-FORMING OROGENY TO OTHER OROGENIES OF REGION

The orogeny forming the hypothetical Ti Valley-Bengal uplift, from which the erratic boulders may have been derived, took place in Pennsylvanian time. This is shown (1) by the stratigraphic superposition of the boulder-bearing Johns Valley shale above approximately 12,000 feet of rocks (Hot Springs, Stanley, and Jackfork) of Pennsylvanian age; (2) by the presence in the Johns Valley shale of fossilferous shale and sandstone strata of Pennsylvania age; (3) by the inclusion in the shale of erratic boulders of fossiliferous limestone of Pennsylvanian age; and (4) by the normal stratigraphic position of the Atoka formation of Pennsylvanian age above the shale.

That the orogeny took place within Pottsville time (early Pennsylvanian), presumably near the middle of the Pottsville, is indicated by the fossil evidence that has been provided by the sequence of Pennsylvanian rocks in the Ouachita Mountains and in adjoining regions.

A lower Pottsville age is assigned by David White to the Pennsylvanian floras thus far obtained from the Stanley and Jackfork formations. The invertebrate fossils from the Jackfork, as stated by G. H. Girty, may or may not be as young as the Morrow group. The youngest limestone erratics and the fossiliferous shale and sandstone strata in the Johns Valley shale are, on the basis of their invertebrate and micro-fossils, comparable with the Wapanucka limestone, the Morrow group, and the Springer formation; they are, therefore, presumed to be in part of middle Pottsville age, which is the age of the flora of the "coal-bearing shale" member of the Morrow group. Invertebrate fossils from beds regarded as basal Atoka are comparable

[65] L. W. Collet, *Les Lacs* (Paris, 1925), p. 195.

[66] N. Yamasaki, "Physiographical Studies of the Great Earthquake of the Kwanto District, 1923," *Jour. Faculty Sci., Imp. Univ., Tokyo*, Vol. 2, Pt. 2 (1926), pp. 98–99.

with the Morrow group and the Wapanucka limestone, but plants from higher portions of the Atoka formation are of upper Pottsville age.

The boulder-forming orogeny appears to have taken place coincident or nearly coincident with a widespread early Pennsylvanian orogeny that, according to C. W. Tomlinson,[67] Sidney Powers,[68] A. I. Levorsen,[69] and Robert Dott,[70] affected a large region in southern Oklahoma, including the Criner Hills and the Arbuckle Mountains. The orogeny described by them followed Morrow and Wapanucka times and preceded Atoka time. In the Ardmore basin of Oklahoma it took place near the middle of Dornick Hills time.

Johns Valley time appears to have been followed by an uplift in the Ouachita region, and by partial erosion of the Johns Valley sediments. This is indicated by the water-laid well sorted conglomerate at the base of the Atoka formation which is widespread though it is comparatively thin.

Deformation involving the Ouachita Mountain sequence within or near the frontal portion of the Oklahoma structural salient produced land ridges in Atoka time, as is shown by the presence of conglomerates composed of novaculite (chert) pebbles in the Atoka formation near Atoka, Oklahoma.[71] The writer's opinion, which is similar to that of F. A. Melton,[72] is that the chert conglomerates near Atoka, Oklahoma, were not derived from the near-by exposures of chert in Black Knob Ridge, but from an uplift which has been concealed underneath the northwestwardly overthrust rocks of the present Ouachita Mountains including Black Knob Ridge.

Further folding of the Ouachita area took place during or after the deposition of the Boggy shale,[73] of Allegheny age.

[67] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 20–27.

[68] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 1049–62.

[69] A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (1928), pp. 37–38.

[70] Robert Dott, "Notes on Pennsylvanian Paleogeography with Special Reference to South-Central Oklahoma," *Oklahoma Geol. Survey Bull. 40-J* (1927), pp. 12–14.
———, "Overthrusting in the Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), pp. 567–602.

[71] J. A. Taff, "Description of the Atoka Quadrangle," *U.S. Geol. Survey Geol. Atlas U.S., Atoka Folio 79* (1902), p. 4.

[72] F. A. Melton, "Age of the Ouachita Orogeny and its Tectonic Effects," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 1 (January, 1930), pp. 57–72.

[73] W. W. Clawson, Jr., "Oil and Gas Geology of Coal and Pittsburg Counties," *Oklahoma Geol. Survey Bull. 40-JJ* (1928), pp. 14–15.

Later in Pennsylvanian time further deformation including thrust faulting doubtless took place, coincident with movements[74] in the Arbuckle Mountains, (1) in middle Pennsylvanian, a little before the end of Wewoka time, and (2) in late Pennsylvanian, near the end of Vamoosa time. The writer agrees with Honess[75] and Powers[76] that the major deformation of the Ouachita Mountain region took place within the Pennsylvanian, but Melton[77] and van der Gracht[78] suggest overthrusting in the Permian.

From the foregoing summary of orogenic movements affecting the Ouachita Mountains and the immediately adjacent areas, it is seen that the boulder-forming orogeny was the earliest of several mountain-making movements that took place in the Ouachita region in Pennsylvanian time. The deposition of Pennsylvanian sediments in the Ouachita (Llanoria) geosyncline took place in response to a still earlier orogeny that initiated mountain-building on the Paleozoic hinterland Llanoria. This early orogeny that caused the erosion of sediments for the Stanley and Jackfork formations was synchronous with uplift and erosion of Appalachia and the consequent deposition of the sediments for the Lookout sandstone of Georgia and Tennessee, and the Lee formation of Tennessee and Virginia, as well as other formations of early Pottsville age in the Appalachian region.

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S. W. Lowman, "Cherokee Structural History in Oklahoma," *Tulsa Geol. Soc. Digest* (1933), pp. 31–34.

[74] G. D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geology Bull. 2* (Norman, Oklahoma, 1924), pp. 19–21.

[75] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923), p. 259.

[76] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 1031–71.

[77] F. A. Melton, *op. cit.*

[78] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 991–1057.
*Ibid., K. Aked. Welensch. Amsterdam Vers., Afd. Natuurk.*, Deel 27, No. 3 (1931).

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# AGE OF JACKFORK AND STANLEY FORMATIONS OF OUACHITA GEOSYNCLINE, ARKANSAS AND OKLAHOMA, AS INDICATED BY PLANTS[1]

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## ABSTRACT

Notwithstanding the ties between the plant species from the Stanley and Jackfork formations and the lower Pottsville floras of the Appalachian trough, the writer was long disposed to regard the two named formations as of very late Mississippian age, largely on account of their close paleobotanical relations to the "Culm" floras of the Waldenburg and Ostrau series, then classed as Mississippian, in the Silesian region. The detailed study of all the available plant material, including an important collection by H. D. Miser of small fern fragments from the upper Stanley near Gillham, Arkansas, completed in 1932, shows that the upper Stanley flora is distinctly later than the flora of the Wedington sandstone member of the Fayetteville shale or than any other known Mississippian flora in eastern North America.

Predominantly the flora is of lower Pottsville composition. Meanwhile, the Ostrau-Waldenburg series was, in 1927, transferred by the Heerlen Congress to the Pennsylvanian. The Jackfork-Stanley is paleobotanically older than the Coal-bearing shale (member in the Morrow group), which is middle Pottsville in age, being post-Lee and post-Raleigh in the Pottsville series of the Appalachian trough. The conclusion that the Jackfork and Stanley may be largely if not wholly equivalent in time to the lower part of the Morrow group finds support in the few plant fragments common to the Hale sandstone.

## PROBLEMS OF JACKFORK AND STANLEY

The Jackfork and Stanley formations, of Carboniferous age, were deposited in the Ouachita geosyncline of western Arkansas and eastern Oklahoma. The more precise age of the formations—the question whether they are Mississippian or Pennsylvanian—has been the subject of persistent differences of opinion and intermittent debate for 30 years. The controversy, due largely to lack of requisite paleontological evidence, has in more recent years been complicated by divergent views as to the sequence and stratigraphic relations of the terranes involved.

The Stanley shale, which underlies the Jackfork sandstone, approximates 6,000 feet in thickness, though 10,000 feet has been re-

[1] Manuscript received, March 14, 1934. Read by title before the Association at the Dallas meeting, March 24, 1934. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

ported[3] in southeastern Oklahoma. It embraces dark, fissile shale, blue or blue-black to black when fresh and bluish or greenish when weathered, interbedded with thin to massive, generally fine-grained and micaceous gray or bluish gray sandstones which in places weather grayish green or drab, and contains, near its base, several thin beds of tuff.[4] Over a very restricted area it lies on the Hot Springs sandstone, a thin formation conglomeratic at the base and regarded as Mississippian, but throughout most of its area, it rests unconformably, with very thin basal conglomerates, on the Arkansas novaculite (Devonian).

The Jackfork sandstone, lying apparently conformably and even transitionally on, and approximately coextensive with, the Stanley, is composed of massive, compact, fine-grained to coarse-grained dark gray-to-light gray sandstones, micaceous and gritty, especially near the base, including smaller amounts of shaly limestones and green, black, or blue arenaceous or argillaceous shale in an aggregate thickness of 5,000–6,500 feet or more.

It is in turn overlain, apparently conformably, by the Johns Valley shale, a deposit with thin intercalated sandstones, locally 1,500 feet thick, formerly designated in most geologic literature as the Caney shale. Locally the marine or true Caney itself rests on the Jackfork. The invertebrate fauna in the upper part of this Caney is classed as Morrow (Pennsylvanian), while that obtained from the lower part is generally correlated with the Moorefield, Batesville, and Fayetteville formations[5]—all of which has led to the prevailing view that the Jackfork and Stanley are Mississippian in age, and they are so mapped by Miser and Branner. A recent contention of the opponents of this view is that the shale yielding the Mississippian fossils owes its superposition on the Jackfork to thrust or landslides.

The Jackfork and Stanley formations, themselves, have yielded very meager marine invertebrate faunas which have hitherto been viewed as consistent with the lower Caney fauna, though insufficient for definite age determination.[6]

[3] C. W. Honess, "Geology of Southern LeFlore and Northwestern McCurtain Counties, Oklahoma, *Bur. Geol. Cir. 3* (1924).

[4] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Amer. Jour. Sci.*, 5th ser., Vol. 2, p. 71 (1921).
C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923).

[5] G. H. Girty, "Fauna of the Caney Shale of Oklahoma," *U.S. Geol. Survey Bull. 377* (1909).
G. D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2* (1924) p. 56.

[6] H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of

The Johns Valley shale is remarkable for the presence of included exotic boulders, comprising fragments of fossiliferous limestones ranging from small cobbles to masses as great as 370 feet long and containing fossils of Ordovician, Silurian, and Mississippian age. These inclusions, many of which are rounded, subangular or angular, and gouged, scraped, or merely scratched and striated, and which are distributed over a considerable area, are regarded as (1) ice transported, (2) products of submarine rock slides, (3) subaerial escarpment talus, or (4) resulting from thrust-fault drag, according to the view of the geologist interrogated. A majority of the regional geologists seem to favor the second or the fourth hypothesis.

The general geology of the Ouachita basin has been represented by H. D. Miser on the geologic map of Oklahoma, published by the United States Geological Survey in 1926, and on the map of Arkansas, by G. C. Branner, issued in 1929 by the Geological Survey of Arkansas. Summary descriptions of the geologic formations and of the geologic structure, together with synopses of the evidence and varying conclusions as to ages and rock sequences, have been compiled by Miser and Honess.[7] Miser[8] now presents new age interpretations based by George H. Girty on invertebrate faunas, and revised conclusions as to the structural history by himself. These new interpretations are, so far as I have learned, in essential agreement with the conclusions reached by me in the detailed study of the fossil plants completed nearly 2 years ago and here summarized at Miser's suggestion. The reader is referred to the latter's contribution[8] for further nonpaleobotanical information.

## AGES OF FORMATIONS AS DETERMINED BY FOSSIL PLANTS

The purpose of this paper is to present the conclusions as to the age of the Jackfork and Stanley formations based by the writer on the study of the plant material in hand in 1931.[9]

It will be noted that, on the paleobotanical evidence, the writer refers not only the Jackfork to the Pennsylvanian, but also the upper

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the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 44* (1927), pp. 5, 16, 17, 18.

[7] *Op. cit.*, pp. 5–27.

[8] H. D. Miser, "Carboniferous Rocks of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), pp. 971–1009.
Bruce H. Harlton, "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *ibid.*, pp. 1018–49.

[9] Submission of the writer's report (1931) embodying the descriptive paleobotanical data for publication by the United States Geological Survey awaits completion of the plant illustrations. In the following paragraphs the writer quotes freely from this manuscript.

half, and, by implication, the non-plant-bearing lower half of the Stanley as well. Previously the Stanley, and possibly the Jackfork, were regarded by the writer as uppermost Mississippian, for reasons to be mentioned later.

In 1904, E. O. Ulrich, then accompanying J. A. Taff in the Tuskahoma Quadrangle, Oklahoma, found in the upper part of the Stanley (or lower part of the Jackfork?) a few fragments of *Lepidodendron* recognized as Carboniferous, probably Pennsylvanian, by him, and on his recommendation both the Jackfork and Stanley were immediately transferred from the Ordovician to the Carboniferous brackets of the geological column. These specimens, with some additional material collected in the same region and east of Atoka by the writer, were then interpreted as probably very late Mississippian. In answer to subsequent persistent inquiry, and with more stem casts and seeds, collected by H. D. Miser, the writer expressed the view that the beds might have been laid down in the very late Mississippian or during an early part of the period of post-Mississippian emergence, which is not represented by plant-bearing deposits yet recognized on this continent. This opinion was based largely on the parallelism in floral composition and the presence of closely related or identical floral elements in the Jackfork and Stanley and in the very fully elaborated floras of the Waldenburg and Ostrau series ("Culm") of the former Austro-Silesian region which were then regarded as uppermost Mississippian, though the floras of the Ouachita region had very much in common with those of the lower Pottsville in the Appalachian trough.

Meanwhile, Charles Schuchert[10] put himself on record as in favor of the Pennsylvanian age of the deposits, largely on account of the presence, in a small collection, of *Lepidodendron* and *Calamites*. The same fossils, including a few invertebrates from the Stanley shale, were examined by Ulrich[11] also, who stated:

> There is nothing in the collection that may be justly cited as definitely opposed to the correlation of the Stanley with the lower Pottsville or basal Morrow, which conclusion I reached in my "Revision" (1911) mainly on physical and diastrophic considerations.[12]

It is due to the deep interest and continuing efforts of H. D. Miser toward the solution of the problem that considerable additional plant material, including small fragments of ferns, was discovered in the upper part of the Stanley shale near Gillham, Arkansas, as well

[10] Charles Schuchert, quoted by H. D. Miser and C. W. Honess, *op. cit.*, pp. 16, 17.

[11] H. D. Miser and C. W. Honess, *op. cit.*, p. 17.

[12] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 22 (1911), pp. 477, 528.

as calamarian, lepidophytic and seed casts in the Jackfork, most of which have been obtained from Devils Hollow near Talihina, Oklahoma. The writer's opinion, based on a preliminary inspection of this material and still influenced largely by the supposed late Mississippian age of the Silesian "Culm" floras, was that the plants from the Stanley, in particular, might be

> of Chester age, but the paleobotanical data available are insufficient to justify their conclusive reference to the Mississippian. The examination suggests the possibility of the deposition of a great thickness of sandstone and shale derived from the north Texas land mass [Llanoria], on the south, during the period of post-Mississippian uplift and deformation and the earliest stages of Pennsylvanian subsidence.

This view is in harmony with that previously expressed by Ulrich, that the Stanley might represent the emergent phase of the Pennsylvanian-Mississippian diastrophic movement, a view that has recently been adopted by van der Gracht.[13]

The detailed studies of the Jackfork and Stanley plants available in the collections of the United States Geological Survey have strengthened the tentative correlation of the Stanley shale with the upper "Culm" of Europe, while they emphasize the extremely close relation between the Jackfork and the early Pottsville in America. In the meantime, however, at the Heerlen Congress (1927), which was attended by a group of paleontologists and stratigraphers especially concerned with the classification of the Mississippian and Pennsylvanian rocks of Europe, it was unanimously agreed[14] that the Ostrau-Waldenburg "Culm" is of Pennsylvanian age. It was, accordingly, placed in the new division, "Namurian," established to constitute the lowest portion of the revised Pennsylvanian system. Thus the floras, through whose close relationship to the Stanley the writer was led to regard the Stanley as uppermost Mississippian, are now classed as basal Pennsylvanian.[15]

The combined floras, comprising but a small aggregate, now in hand from the Jackfork and Stanley embrace 32 species, of which 25 occur in the Stanley and 17 in the Jackfork, 8 being common to both. Nearly all the "fern" fragments were collected by Miser from the

[13] W. A. J. M. van Waterschoot van der Gracht, "The Permo-Carboniferous Orogeny in the South-Central United States," *Verh. d. Kon. Akad. Wetensch. Amsterdam Natuurk.*, 2d ser., Vol. 17, No. 3 (Amsterdam, 1931), p. 10. Also *ibid.*, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 991–1057.

[14] Congrès pour l'avancement des Études de Stratigraphie Carbonifère: Heerlen, 7–11 Juin, 1927; *Comptes Rendus*, pp. I–LIII.

[15] While the Pennsylvanian age of most of the transferred terranes is not now doubted, the inclusion of the beds containing *Cardiopteris* and *Lepidodendron volkmannianum* seems questionable.

upper Stanley, but several seeds in the Jackfork assure the presence of pteridosperms in the latter also. Taking the seeds into account, it is probable that half of the Jackfork flora is also present in the Stanley. The joint flora embraces calamitic and lepidophytic types as well as pteridosperms in a typical lower Pennsylvanian assemblage, and although very meager and represented by fragments often of insignificant size, it probably presents a fair cross section of the floral characteristics of both formations. While additional collections will undoubtedly reveal more genera and species, the general complexion of the flora and its proportionate relations are not expected to change seriously as a result of further search.

In the region embracing the Ouachita geosyncline there are only two formations, one of late Mississippian, the other of early Pennsylvanian age, the floras of which have been described and which are close enough in age to our flora for crucial or even critical comparisons. They are the Wedington sandstone member of the Fayetteville shale and the "Coal-bearing shale" of the Morrow group. The older, the Wedington sandstone, contains a flora, described by the writer in an unpublished manuscript, that is typical of the Chester. It is in close agreement with the Chester flora as found in southern Illinois, Indiana, western Kentucky, and several regions of the Appalachian trough. None of the species characteristic of the Wedington or of the Chester of the eastern basins is present in the Jackfork or Stanley.

> The examinations and comparisons leave no recourse but to conclude that both the Stanley shale and Jackfork sandstone are younger than the Wedington sandstone member. The difference is relatively distinct, though the floral representations in hand are relatively small. There appears, therefore, to remain little or no doubt that the Stanley as well as the Jackfork is younger than the entire Fayetteville shale and its Mississippian correlates.[16]

Paleobotanically the Morrow group (Pennsylvanian) which rests unconformably on the Pitkin limestone, of Chester age, is known almost solely by the flora of the "Coal-bearing shale," a thin member in the lower part of the Bloyd shale and at about the middle of the group. Next to the shale at Mazon Creek, Illinois, the "Coal-bearing shale," of Washington County, Arkansas, is paleobotanically the most fully explored deposit in the Carboniferous of the United States. In Arkansas about 125 plant species have been found in it, and these clearly and unmistakably correlate the terrane with the Sewanee shales, above the Lookout formation in Alabama and Tennessee; the Norton formation, above the Lee, in southwestern Virginia; the Sewell

[16] Quoted from manuscript written in 1931–32 describing the Jackfork and Stanley floras.

formation of central and southern West Virginia; and the lower part of the Upper Lykens group of coals in the Southern Anthracite region of Pennsylvania. All these are of middle Pottsville age, as also is the Caseyville formation of southern Illinois and western Kentucky. A study of the relations and distribution of the elements in the Jackfork and Stanley floras shows that the deposits are distinctly older than the plant life of the "Coal-bearing shale," there being but two species definitely recognized as present also in the latter.

Taking into account the middle Pottsville age of the "Coal-bearing shale," as shown by the fossil floras, it may be provisionally concluded that the lower portions of the Morrow group are more or less fully equivalent to the lower Pottsville of the Appalachian trough. Unfortunately little is known either as to the flora of that portion of the Morrow group lying below the "Coal-bearing shale," or as to marine faunas in the lower Pottsville of the eastern basins. A few stem casts and impressions of *Lepidodendron* found by Miser in the Hale sandstone, the basal unit of the Morrow group, point toward the complete inclusion of the Morrow in the Pennsylvanian, but these plant remains are not of a nature to permit a more restricted reference of the Hale.

It is to the early Pottsville, of pre-"Coal-bearing shale" time, specifically the lower Pottsville, which embraces the Lookout sandstone of Georgia and Tennessee, the Lee formation of Virginia, and the Pocahontas, Fire Creek, and Raleigh stages of West Virginia, and the Lower Lykens group of the Southern Anthracite field in Pennsylvania that the Jackfork is referred, with probability that the whole Stanley falls in the same unit of the lower Pennsylvanian.

The Jackfork sandstone has not yet revealed any plant association that can be regarded as Mississippian in age—not to mention a stage so low in the Mississippian as that to which the lower part of the Caney shale is generally referred.

The Atoka sandstone of Oklahoma, also derived from Llanoria, passes laterally into the Winslow formation of Arkansas, and is evidently largely equivalent to it. The Atoka lies on the Johns Valley shale locally and is described as resting on the Caney shale near Wesley and Ti, Oklahoma, on the Wapanucka limestone (Morrow age) at the top of the Caney between LeFlore and Stringtown, Oklahoma, and even on beds as old as the Woodford chert, near Bengal, Oklahoma. The Winslow rests unconformably on the Morrow group and is nowhere seen on any formation of later date, whence, it is believed that the Atoka, as well as its near equivalent, the Winslow, is, for the most part at least, post-Morrow in age.

Little paleobotanical material has been gathered from the Atoka, but the small amount examined belongs to a stage as high as, or probably higher than, the "Coal-bearing shale" of the Morrow. There remains, therefore, no evidence of weight to prove that the Jackfork and Stanley formations are of Mississippian age, excepting the long as well as widely accepted superposition of shale of Mississippian age on the Jackfork. That this superposition, observed at only a few points, is normal rather than by thrust the writer profoundly doubts. Otherwise, there is a marine Chester fauna in beds, correlated with the Moorefield shale, the Fayetteville shale, and the Batesville sandstone, overlying Llanoria-derived beds which the writer can view only as in their entirety Pennsylvanian and as probably not earlier than the earliest known Pottsville[17] of the Appalachian trough.

It may be asked, however, whether we have to do with an adventitious or "precocious" flora or a "hold-over" fauna. There is nothing in the general makeup of the floras, in the characters developed or in the association of the genera and species that appears abnormal or out of order. On the other hand, there is little in the way of marine invertebrates reported from the lower Pottsville of the Appalachian trough for use in any attempt to correlate lower Morrow or other probably basal Pennsylvanian formations of any other region.

[17] A very rude estimate of the volume of sediments composing the remaining portions of the Jackfork sandstone and the Stanley shale indicates more material than would suffice to construct a mountain range 12,000 feet high, with appurtenant spurs and foothills, reaching from Atoka, Oklahoma, to Little Rock, Arkansas, a distance of about 200 miles. That such orogenic movement, synclinal deformation, and erosion took place within very late Chester time and constitute a distinct episode completed so little before the post-Mississippian uplift without being a part of that uplift is highly improbable.

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# CARBONIFEROUS STRATIGRAPHY OF THE OUACHITAS WITH SPECIAL STUDY OF THE BENDIAN[1]

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## ABSTRACT

On the basis of paleontological and diastrophic evidence a new period is proposed under the name Bendian to include that part of the section between the Chester group of Mississippian age and the Des Moines series of Pennsylvanian age. The Bendian period in the Mid-Continent is divided into Lower Bendian, Middle Bendian, and Upper Bendian.

In the Ardmore basin, where the micro-fauna is profuse, the Lower Bendian is represented by the basal Springer formation, the Middle Bendian by the middle and upper Springer formation, and the Upper Bendian by the lower and middle Dornick Hills formation. To these formations are correlated definitely the Hot Springs sandstone, Stanley shale, Jackfork sandstone, and Johns Valley shale, the Bendian representatives in the Ouachita Mountains.

The Carboniferous stratigraphy of the Ouachita Mountains is made up of the Mississippian portion of the Arkansas novaculite, the Bendian Hot Springs sandstone, Stanley shale, Jackfork sandstone, and Johns Valley shale, and the Pennsylvanian Atoka formation. These formations are described with special emphasis on the micro-faunal data by which correlations have been made with other Bendian localities in Oklahoma, Arkansas and Texas, and the collections from all these places were minutely scrutinized.

## INTRODUCTION

The suite of Pennsylvanian rocks now known as "Bend" was first designated as a unit by Dumble[3] in 1890, and was more fully defined by Cummins[4] as a distinctive group in 1891, but it was not until 1924 that Schuchert[5] recognized that the rocks deposited during this time represented a definite epoch, which he proposed to call the "Bendian" in his correlation chart published that year.

After many years of gathering data, and in consideration of both the faunal and diastrophic evidence, of which only a minor part could be adequately presented at this time, the writer proposes an important change in the late Paleozoic part of the column by adding the dis-

[1] Manuscript received, April 17, 1934. Published by permission of the Amerada Petroleum Corporation.

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[3] Edwin Theodore Dumble, "Report of the State Geologist for 1889," *Texas Geol. Survey Ann. Rept. 1* (1890), pp. xvii–xc; map.

[4] William Fletcher Cummins, "Report on the Geology of Northwestern Texas," *Texas Geol. Survey Ann. Rept. 2* (1890), pp. 357–552.

[5] Charles Schuchert, *A Textbook of Geology*, Pt. 2, p. 353, revised, 1924. John Wiley and Sons, Inc., New York.

tinct and sharply defined Bendian[6] period. This new period, which seems an imperative necessity, comprises stratigraphic units previously known in the standardized section of the Mississippian and Pennsylvanian, and under this term are included all the formations in the Llanoria geosyncline[7] younger than Chester and older than Des Moines. An important stratigraphic hiatus separates the Mississippian in the Ouachitas and other areas from the overlying Bendian. The opening of the succeeding Pennsylvanian period is marked by an important and widespread diastrophic and faunal break. The general Bendian facies are to a large extent like those of the Pennsylvanian.

That the Bendian constitutes a well delimited period will scarcely be denied by those who have adequate field and laboratory data and experience wide enough to include all the areas concerned, and the writer wishes to expand the term to include a period of geological time which has a distinct history. This period of time embraces many other formations both older and younger than the two Texas formations originally included in the Bend. Schuchert has expanded the Bendian to include many of these formations also, but the writer has added others which are evident on the correlation chart. The areal extent of the Bendian rocks and the upper and lower limits at certain localities have always been in considerable doubt because of the scarcity of megascopic fossils in the thick series of clastic sediments which dominate the deposits throughout.

With the increasing recognition of micro-fauna in the Carboniferous section in the Mid-Continent it has been possible to work out faunal assemblages which permit definite correlation of certain shale, sandstone and limestone formations previously placed in doubtful correlation with entirely different formations, due to lack of diagnostic fossils.

As a result of extensive, detailed study of Paleozoic micro-fauna in the field and laboratory during the past 8 years, the writer submits a new classification of the Bendian of the southwestern United States, based upon definite evidence which shows the inaccuracy of previously accepted correlations.

Briefly, the Bendian period is divided into three subdivisions Lower Bendian, Middle Bendian, and Upper Bendian, each with its distinctive faunal assemblages, which have been recognized in the major Bendian provinces—the Ouachita Mountains of Arkansas and

[6] The term "Bendian," a modification and restriction of the name "Bend series," seems highly appropriate.

[7] H. E. Sellards, "The Pre-Paleozoic and Paleozoic Systems in Texas," *Univ. Texas Bull.* 3232 (1932), p. 23.

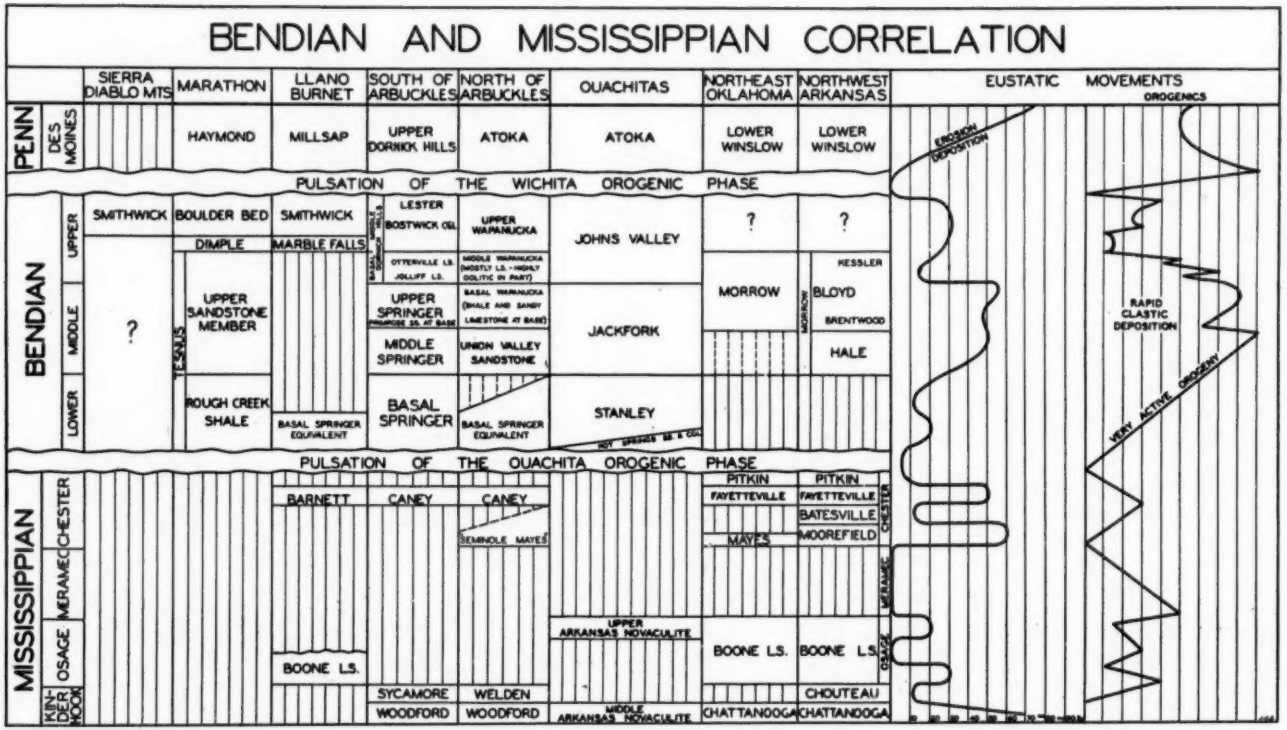
BENDIAN AND MISSISSIPPIAN CORRELATION
SIERRA DIABLO MTS
MARATHON
LLANO BURNET
SOUTH OF ARBUCKLES
NORTH OF ARBUCKLES
OUACHITAS
NORTHEAST OKLAHOMA
NORTHWEST ARKANSAS
EUSTATIC MOVEMENTS
OROGENICS
PENN
DES MOINES
HAYMOND
MILLSAP
UPPER DORNICK HILLS
ATOKA
ATOKA
LOWER WINSLOW
LOWER WINSLOW
EROSION DEPOSITION
PULSATION OF THE WICHITA OROGENIC PHASE
BENDIAN
UPPER
MIDDLE
LOWER
SMITHWICK
BOULDER BED
DIMPLE
UPPER SANDSTONE MEMBER
ROUGH CREEK SHALE
TESNUS
?
SMITHWICK
MARBLE FALLS
BASAL SPRINGER EQUIVALENT
LESTER
BOSTWICK CGL.
OTTERVILLE LS.
JOLLIFF LS.
UPPER SPRINGER
PRIMROSE SS. AT BASE
MIDDLE SPRINGER
BASAL SPRINGER
UPPER WAPANUCKA
MIDDLE WAPANUCKA (MOSTLY LS. - HIGHLY OOLITIC IN PART)
BASAL WAPANUCKA (SHALE AND SANDY LIMESTONE AT BASE)
UNION VALLEY SANDSTONE
BASAL SPRINGER EQUIVALENT
JOHNS VALLEY
JACKFORK
STANLEY
HOT SPRINGS SS. & CGL.
?
MORROW
?
KESSLER
BLOYD
BRENTWOOD
HALE
MORROW
PULSATION OF THE OUACHITA OROGENIC PHASE
RAPID CLASTIC DEPOSITION
VERY ACTIVE OROGENY
MISSISSIPPIAN
CHESTER
MERAMEC
OSAGE
KINDERHOOK
BARNETT
BOONE LS.
CANEY
SYCAMORE
WOODFORD
CANEY
SEMINOLE MAYES
WELDEN
WOODFORD
UPPER ARKANSAS NOVACULITE
MIDDLE ARKANSAS NOVACULITE
PITKIN
FAYETTEVILLE
MAYES
BOONE LS.
CHATTANOOGA
PITKIN
FAYETTEVILLE
BATESVILLE
MOOREFIELD
BOONE LS.
CHOUTEAU
CHATTANOOGA
CHESTER
MERAMEC
OSAGE

FIG 1

Oklahoma, the Ardmore basin of Oklahoma, the Central Mineral region, the Marathon area, and the Sierra Diablo and Franklin mountains of Texas.

In Oklahoma a remarkably prolific and diagnostic Bendian microfauna occurs in the Springer and the lower and middle Dornick Hills formations of the Ardmore basin and serves as the type fauna, for the subdivision of the Bendian. The basal Springer represents the Lower Bendian, the middle and upper Springer represent the Middle Bendian, and the lower and middle Dornick Hills formation inclusive of the Lester limestone is Upper Bendian. Bendian exposures elsewhere, as shown in chart (Fig. 1) are correlated by their micro-fauna with that of the Ardmore basin Bendian.

The basal Springer formation of the Ardmore basin, as here defined, includes the upper part of the Caney shale as mapped by Tomlinson,[8] as well as his basal Springer. It is made up mainly of clastic sediments, but has yielded only a few poorly preserved and undiagnostic megasopic fossils. However, at its outcrops a profuse assemblage of Lower Bendian microscopic fossils has been found in this bulk of sediments. The base of the Springer formation is drawn by Tomlinson at the bottom of the Rod Club member. This sandy member is not exposed everywhere,[9] and since the underlying shales are lithologically and faunally identical with those above the Rod Club member, the author submits the need of extending the base of the Springer formation to the base of the Bendian shales. A good exposure of this shale is found just north of Ardmore on the Caddo anticline, near the center of the S. ½, SE. ¼, Sec. 1, T. 4 S., R. 1 E., Carter County, Oklahoma.

The micro-fauna of the basal Springer is decidedly in contrast to that of the Mississippian Caney shale. This contact should be clear to anyone having a comprehensive knowledge of the stratigraphy and faunas of these formations, although several simulating Chester genera, all of which are very distinct specifically, continued to live throughout Bendian time. The profuse amount of new life, especially tubicular annelids, free-swimming forms such as conodonts, represented by detached jaws and toothed plates, *Ostracoda*, and in particular the *Foraminifera*, make the Mississippian reminders practically negligible.

The Middle Bendian, which is represented by the middle and upper Springer formations of the Ardmore basin, is characterized mostly by massive sandstones and silty shales (Fig. 2). The micro-faunal as-

[8] C. W. Tomlinson, "The Pennsylvanian System of the Ardmore Basin, Oklahoma," *Oklahoma Geol. Survey Bull. 46* (1929).

[9] C. W. Tomlinson, *op. cit.*, p. 16.

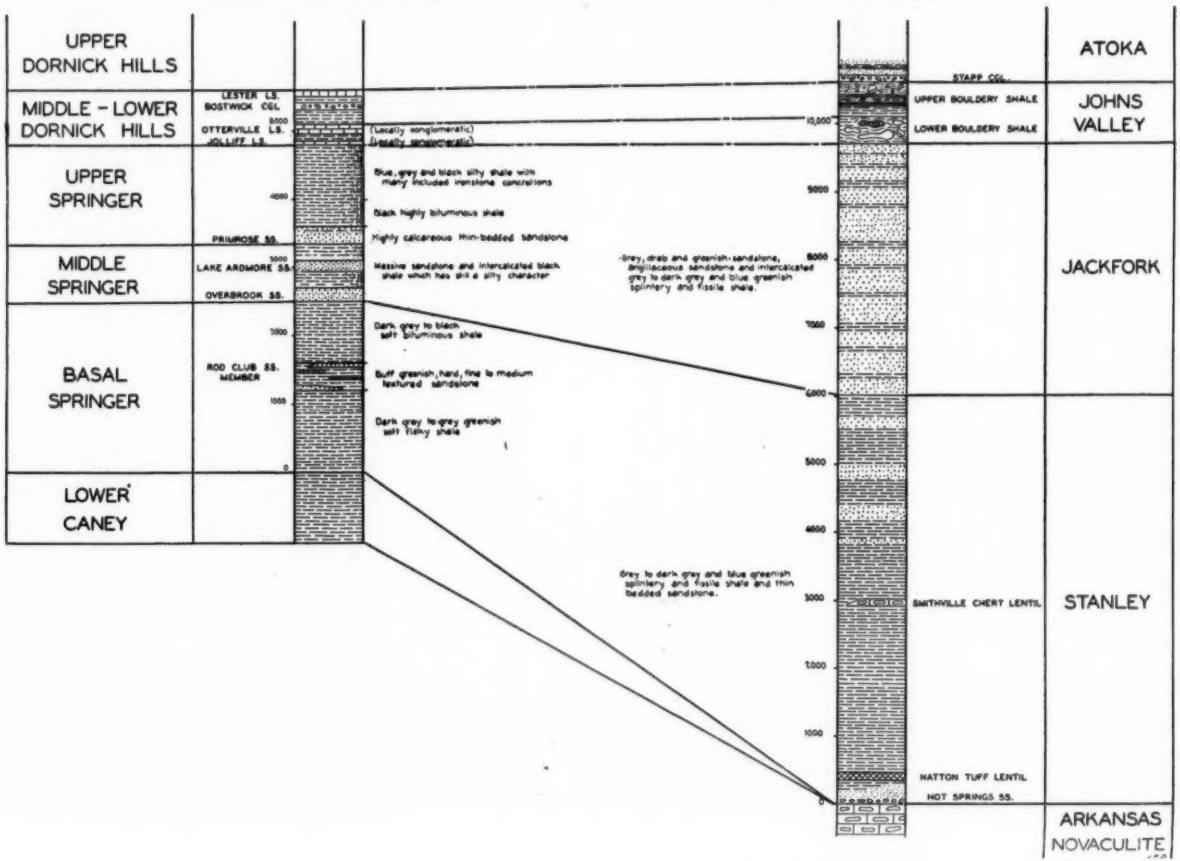
ARDMORE BASIN
OUACHITA MTS.
UPPER DORNICK HILLS
MIDDLE - LOWER DORNICK HILLS
UPPER SPRINGER
MIDDLE SPRINGER
BASAL SPRINGER
LOWER CANEY
LESTER LS.
BOSTWICK CGL.
OTTERVILLE LS.
JOLLIFF LS.
PRIMROSE SS.
LAKE ARDMORE SS.
OVERBROOK SS.
ROD CLUB SS. MEMBER
(Locally conglomeratic)
(Locally conglomeratic)
Blue, grey and black silty shale with many included ironstone concretions
Black highly bituminous shale
Highly calcareous thin-bedded sandstone
Massive sandstone and intercalated black shale which has still a silty character
Dark grey to black soft bituminous shale
Buff greenish, hard, fine to medium textured sandstone
Dark grey to grey greenish soft flaky shale
Grey, drab and greenish sandstone, argillaceous sandstone and intercalated grey to dark grey and blue greenish splintery and fissile shale.
Grey to dark grey and blue greenish splintery and fissile shale and thin bedded sandstone.
STAPP CGL.
UPPER BOULDERY SHALE
LOWER BOULDERY SHALE
SMITHVILLE CHERT LENTIL
NATTON TUFF LENTIL
HOT SPRINGS SS.
ATOKA
JOHNS VALLEY
JACKFORK
STANLEY
ARKANSAS NOVACULITE

FIG. 2.—Chart showing Bendian correlatives of Ardmore basin and Ouachita Mountains.

semblage differs greatly from that of the Lower Bendian. The *Sherbonites* of the basal Springer came to complete extinction. Many new genera and species of *Foraminifera* made their first appearance and new fenestelid types of *Bryozoa* became abundant.

It is important to remark that the entire Springer sequence is characterized by irregularly spaced, thin layers or laminae of siderite and siderite concretions, which, due to surface exposure, have undergone the usual process of alteration to limonite. These siderite layers and concretions are undoubtedly precipitates of swamp water containing great amounts of vegetable acid, and appear to indicate the proximity of land deposits.

At the close of Middle Bendian there was undoubtedly broad subsidence into basins of varying depth adjacent to emerging mountains, such as the Criner Hills, which received finer silts and calcareous deposits, producing the dark shales and limestones and local conglomerates of the lower and middle Dornick Hills formation. This includes the beds from the Jolliff limestone through the Otterville limestone, the Bostwick conglomerate, and the Lester limestone. These greatly changed environmental conditions produced notable variations in the micro-faunal assemblage, with the result that the *Foraminifera* and *Ostracoda* reached a remarkable development and are by far the most abundant element of the Upper Bendian fauna. Conodonts and *Bryozoa* also abound in profusion.

During Upper Bendian time considerable limestone was deposited in restricted basins. The geographic pattern must have varied greatly from time to time, as is evident by the widely recognizable faunas and formations that fall into this stage of alternate tilting of the continental platform. Alternating differential movements east and west caused considerable overlap by deposits over most of the area. With these various movements and warpings of the surface of the continent the geographic pattern was ever changing. The history of the movements that caused these changes in distribution of land and sea areas is extremely complex. Oscillation must have been relatively rapid, as evidenced by the frequent hiatuses and rapidly changing lithologic character.

The new environment was conducive to the development of a profuse micro-fauna, which shows such variations in genera and species that subdivisions of the Upper Bendian can be made readily. On the basis of this micro-faunal evidence, the age relationships of the Morrow group of the Ozarks, with its basal Hale formation, the Wapanucka limestone of the Arbuckles, the Otterville limestone of the Ardmore basin, and the Marble Falls limestone of Texas, which have

FIG. 2.—Chart showing Bendian correlatives of Ardmore basin and Ouachita Mountains.

been considered contemporaneous, can now be determined as divergent.

The micro-fauna of the Hale formation, basal member of the Morrow group, consists largely of *Bryozoa* which are without exception allied to older genera and species found in eastern formations. While these faunas were invading from the east, the Union Valley sandstone[10] of the Arbuckle Mountains and the middle Springer formation of the Ardmore basin, which are correlatives of the Hale formation, were being deposited with typical micro-faunas of southern origin in abundance. The presence of *Pentremites* and several *Bryozoa* in the Brentwood limestone which overlies the Hale formation also suggests an eastern origin for the deposits in the Ozark area.

In the basal part of the Wapanucka limestone (middle Wapanucka)[11] in the Arbuckle area the typical Kessler fossils are conspicuously fewer in number, while the *Foraminifera* and *Ostracoda* of southern origin are copiously preserved. This condition was probably brought about by the southwestward tilt of the Arbuckle land area which made possible the invasion of the sea from the south, causing contamination and mixture of the eastern Kessler faunas with the southern faunas in the Wapanucka limestone.

The source and general aspect of the Wapanucka limestone and of the Otterville faunas of the Ardmore basin are similar. In the Bostwick member, there appear the first primitive fusulinids, which are slightly younger than those occurring in the Marble Falls limestone of Texas.

Thus by recognition of the varying characteristics of the profuse Upper Bendian micro-fauna, it is definitely established that the Hale formation is a correlative of the Union Valley sandstone and the middle Springer formation, and therefore older than the Wapanucka. The Wapanucka limestone (middle Wapanucka) is found to be contemporaneous with the Otterville limestone of the Ardmore basin,

[10] R. V. Hollingsworth, "The Union Valley Sandstone," abstract, *Pal. Soc. America*, December, 1933.

[11] It is probable that Harlton's middle Wapanucka is the Wapanucka limestone mapped by Taff at the town of Wapanucka. Since Taff did not designate a type locality, the town of Wapanucka must be so considered. Harlton's basal Wapanucka has been mapped as Caney and as Wapanucka. His upper Wapanucka has usually, if not always, been included in the Atoka formation. There seems to be little doubt that all the rocks Harlton includes in the Wapanucka formation are of Bendian age, being more closely related structurally and faunally to the Wapanucka limestone exposed at Wapanucka than to overlying and underlying formations. This group of rocks needs a great deal more study than Harlton has been able to give—which study would probably result in the naming of new formations. For the time being, Harlton's explanation of the term Wapanucka is useful in grouping together a section of rock which unfortunately in the past has been mapped with more distantly related formations.—Committee on Geologic Names and Correlations, Ira H. Cram, chairman.

which is definitely older than the Marble Falls of Texas. Previously all these formations were considered contemporaneous.

Detailed field investigation indubitably will reveal the equivalents of the middle Dornick Hills in the area north of the Arbuckles as well as in the Ozarks. A reconnaissance study indicated to the writer that these are present north of the Arbuckle Mountains and that at least part of them are present in the Ozarks. These sediments have at least in part been mapped with the lower Atoka formation, but due to the lithologic and faunal characteristics of the Wapanucka, the writer includes these Upper Bendian beds in the Wapanucka formation, using the term upper Wapanucka. This zone is characterized by relatively thick shale bodies intercalated with thin limestone beds with a few thin sandstones. The section is marked by a rather rapid gradation in lithologic character. It is important to note that in the upper portion of this zone a profuse amount of fusulinids occur, and are found in both shales and impure limestones. Furthermore, a few conglomeratic layers are found, which are of local development. Locally toward the base of this zone two sandstones are present, one containing sponges and sponge spicules, and another made up almost entirely of gastropods. Excellent exposures of this zone may be found along Coal Creek, in the SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 15, T. 1 N., R. 7 E., Pontotoc County, and in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 19, T. 1 N., R. 8 E., Coal County, Oklahoma. Overlying the upper Wapanucka at the latter locality, massive, semi-quartzitic, calcareous sandstones and some intercalated shales are found and are correlated with the Chickachoc chert lentil and the conglomerates found at Stapp, Oklahoma.

Following the deposition of the uppermost member of the Bendian, a distinct faunal break occurs in central Oklahoma, north-central Texas, and the Marathon area of Texas, which was followed by widespread deposition of the upper Dornick Hills formation of the Ardmore basin, the Atoka formation of the Ouachitas, and their equivalents. The basal deposits of this post-Bendian series were occasionally conglomerates such as the conglomerate member at the base of the Atoka formation at Stapp and Lamberson Spur, Oklahoma. These coarse clastics herald one of the important orogenic paroxyms. During this mountain-building phase structures of huge dimensions were formed. Elsewhere the post-Bendian begins with a thick series of gray marine shales with sandstone and minor limestone intercalations. Local conglomerates are found at several places throughout the Atoka formation, evidencing minor episodes of uplift.

The Bendian period is notable for its many distinct and widely

recognizable faunal assemblages. Especially important and interesting are some of the simulating faunas of Chester age, whose longevity continued throughout Bendian time. This is explainable by recurring invasions of slowly modifying faunas. Some of these fossils which were

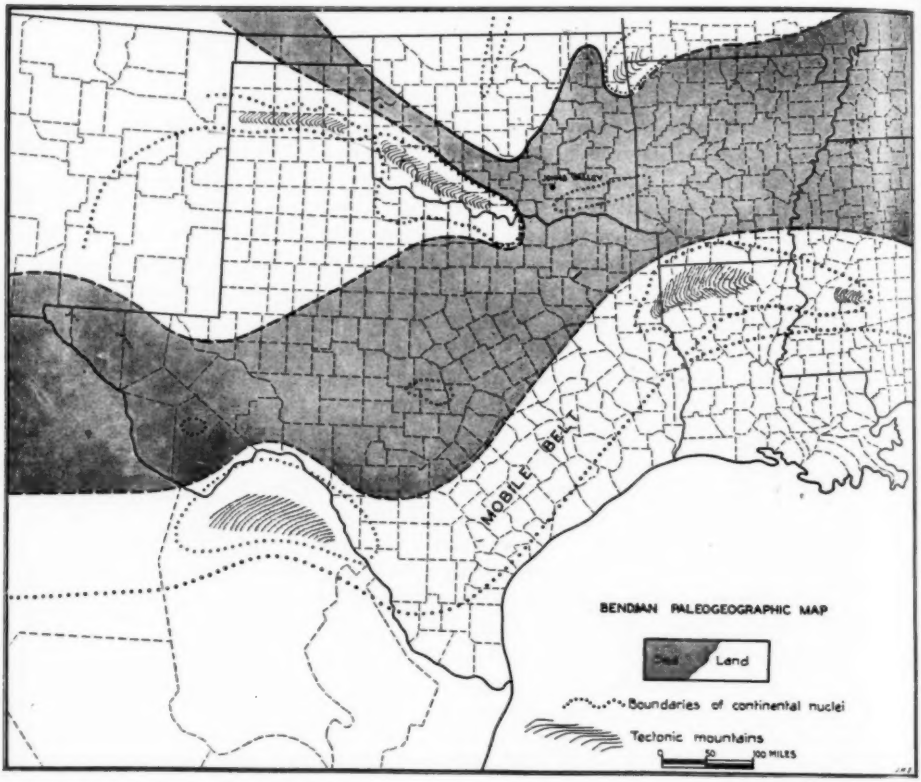


FIG. 3

subject to successive recurrences are difficult to distinguish, while others, in particular the *Bryozoa*, show distinct modification in specific expressions. Most of the incoming organisms had characteristics of their own and were exterminated at the close of the Bendian. Many of the Upper Bendian *Ostracoda* belonging to the family *Beyrichiidae* and *Kirkbyidae* became highly specialized and were rela-

tively short-lived and limited in geographic distribution. The maximum development of the Bendian is found in southern Oklahoma, west-central Arkansas, and north-central and southwestern Texas, indicating that the faunal supply in Bendian time entered from the southwest and the Pacific (Fig. 3). In this connection it is important to note that Bendian faunas have been found in the Parkwood formation of Alabama and Tennessee, and on the basis of paleontologic and lithologic evidence this formation is correlated with the Stanley shale of Oklahoma and Arkansas. Other Bendian exposures, not shown on the paleogeographic map, are known in Colorado, Nevada, and Montana.

### HISTORY OF BENDIAN IN OUACHITA MOUNTAINS

In the Ouachita Mountains sedimentary conditions during the Bendian were similar to those of the Ardmore basin area. The Lower Bendian is represented by the Stanley shale, and the Middle Bendian by the Jackfork sandstone. The most impressive characteristic of these formations is the great volume of clastic deposits of undoubted deltaic origin. Ripple marks, rill marks and crossbedding are evident in many places, with rapid variation from sand to shale throughout the great thickness of sediments. Furthermore, marine fossils are found only in thin streaks, while plant remains of continental derivation are common. This great thickness of clastic sediments is represented by a thinner section elsewhere, indicating very rapid sedimentation which is strongly suggestive of deltaic deposition. The sudden development of this rapid sedimentation is evidence of rapidly rising mountains on the south, which supplied poorly assorted materials to the adjacent seas.

The stratigraphic position of the Stanley and Jackfork formations has been in a state of flux and uncertainty for many years due to lack of megascopic fossils. However, micro-faunal assemblages in these formations are identical with those of the correlatives in the Ardmore basin, indicating definite interchange of deposits, which may also be observed by the physical criteria previously mentioned.

It is deserving of remark that because of oscillatory movements sedimentation occurred at different intervals during Stanley time in shallow offshore lagoons. Spore-bearing plants abounded in their semi-brackish and stagnant waters. The fossil spores found are very different in generic and specific expression from those of the Mississippian and bear a striking resemblance to those found in the Atoka formation. Facts like these furnish additional evidence as to the post-

Mississippian age of the Stanley shale, conforming to the microfaunal evidence.

The Upper Bendian marine sediments are represented in the Ouachita Mountains by the Johns Valley shale, which contains a fauna identical with the lower and middle Dornick Hills formation of the Ardmore basin. The unusual feature of the Bendian in the Ouachitas, to which attention has repeatedly been called, is the presence of pre-Bendian shale, sand, pebbles, cobbles, and boulders imbedded as conglomeratic masses or individual specimens at various positions in the series from the basal conglomerate noted at Boles, Arkansas, through intraformational conglomerates to the Johns Valley shale and the basal post-Bendian conglomerate found at Lamberson Spur and Stapp, Oklahoma. The most extraordinary of these occurrences is that of the tremendous blocks of Ordovician limestone imbedded in the Upper Bendian Johns Valley shale with masses of Mississippian Caney shale closely associated as exotics. There is little controversy regarding the transportation from the outcrops of the other occurrences of pre-Bendian exotics, but the boulders in the Johns Valley shale have given rise to many ingenious explanations, such as floating ice, ice rafting, submarine landslides and mud flows, none of which fits all the conditions satisfactorily.

The bouldery shales are lithologically identical, except for the boulders, with beds of the same age elsewhere south of the Arbuckle Mountains and in Texas, indicating widely similar conditions of deposition except in the Ouachita salient, where modifying conditions, whatever they were, resulted in the inclusion of the boulders.

The Mississippian Caney shale at its type locality in Johns Valley and in the exposed belts along the Windingstair Mountain fault and near Boles, Arkansas, is regarded by Ulrich[12] and the writer[13] as a *remanié*. Masses of this shale with its abundant fossils, limestone concretions, were transported in Bendian time to their present position. Therefore, the name "Caney" should be used in the Ouachitas only in referring to the masses of shale transported from other areas. The exposures of Caney shale along the Ti Valley fault are regarded as autochthonous.

The origin and genesis of the exotics in the Ouachitas is closely related to the complicated structural history and will be discussed in a later paper. Much work remains to be done, which will necessitate

[12] E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927), p. 40.

[13] Bruce H. Harlton, "Micropaleontology of the Pennsylvanian Johns Valley Shale of the Ouachita Mountains, Oklahoma, and Its Relationship to the Mississippian Caney Shale," *Jour. Pal.*, Vol. 7 (1933), pp. 5, 6.

the investigation of many stratigraphic and tectonic details, and testing them in the field will alone reveal the truth.

There is a strong possibility that some of the deposits have been derived from exposed outcrops across which the Ouachita rocks were overthrust northward, and that mud flows carried a great portion of the boulders to their present position. The occurrence of these boulders at a definite stratigraphic position in the sequence appears to indicate that they are an unusual type of sedimentary deposit. Most of the Caney shale exotics, together with older Paleozoic exotics, have usually been incorporated in shale known as Johns Valley of Upper Bendian age.

This entire shale section exposed along Cane Creek in Johns Valley, Twps. 1 N. and 1 S., R. 16 E., Pushmataha County, Oklahoma, was used by Taff as the type locality of the Caney shale. However, more recent usage has restricted the name Caney shale to black shales of Mississippian and Pennsylvanian age, occurring north and northeast of the Arbuckle Mountains and also near Wesley and Ti in the northeast margin of the Ouachita Mountains. One of the best known exposures is found just south of Ada, in the Frisco Railway cut in the southeastern part of T. 3 N., R. 6 E., Pontotoc County, Oklahoma. The Caney as mapped north of the Arbuckle Mountains includes not only the Mississippian portion of the Caney, but the basal Springer equivalent, the Union Valley sandstone, and even the lower Wapanucka shale.

At several outcrops north and northeast of the Arbuckles, brown calcareous shale about 9 feet in thickness is found underlying the Mississippian Caney shale. It is important to note that at the base of this shale a glauconitic zone occurs, which rests on a thin highly glauconitic bed, which Cooper[14] named the Welden limestone. An excellent exposure may be observed in the NE. $\frac{1}{4}$ of Sec. 2, T. 1 N., R. 6 E. Pontotoc County, Oklahoma.[15] Lithologically this body of shale differs conspicuously in color as well as in its highly calcareous content from that of the Mississippian Caney shale, and undoubtedly is related in age to the Welden limestone.

In any discussion of the stratigraphy of the Ouachitas it is necessary to keep in mind the fact that major orogenic movements occurring long after the Atoka deposition have complicated the problem of accurate determination of the thickness and sequence of beds and the details of their deposition. The history of movements, which con-

[14] C. L. Cooper, unpublished manuscript.

[15] Attention was first called to this locality by John Fitts.

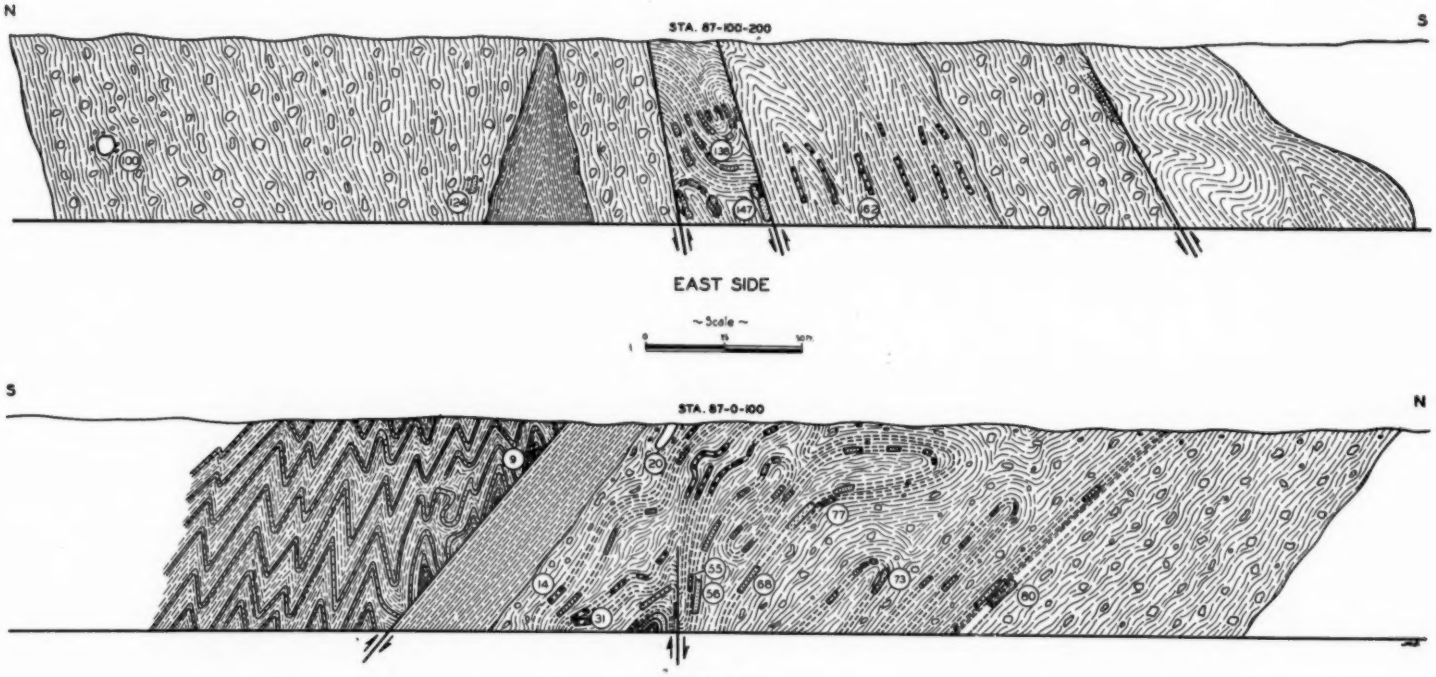


FIG. 4.—Detailed geologic cross section of Compton Cut. Incompetent beds show evidence of flowage.

sisted largely of overthrusting with resultant faulting, folding, tilting, and crumpling of incompetent beds, still has many controversial features, but satisfactory interpretations have been made by Ulrich,[16] Miser,[17] Powers,[18] van der Gracht,[19] and others. As a result of these movements it is evident that the area of deposition of Ouachita sediments before the folding must have differed from and been greater than the area of the mountains at the present day. The overthrust sheets of these deposits lay originally south of their present position.

A Bendian paleogeographic map (Fig. 3), two correlation charts (Figs. 1 and 2), two cross sections (Fig. 4) and six photographs of the exposures at Compton Cut on the Frisco Railroad (Figs. 6 and 7), and one cross section of the exposures from Lamberson Spur (Fig. 5) are given to show conditions briefly described in the text. Furthermore, one plate (Fig. 8) showing some of the pebbles in the bouldery shale from Compton cut is given.

## CARBONIFEROUS STRATIGRAPHY OF OUACHITA MOUNTAINS

In order that the stratigraphic relationships of the Bendian period in the Ouachita Mountains may be clearly understood, it is essential to consider subjacent and superjacent formations. To this end the complete Carboniferous stratigraphy of the Ouachitas is described in detail.

The earliest Carboniferous deposits were the Arkansas novaculite of Mississippian age. Following its deposition the Bendian deposits were laid down, the oldest being the Hot Springs sandstone and the Stanley shale of Lower Bendian age, succeeded by the Jackfork sandstone of Middle Bendian age, and the Johns Valley shale of Upper Bendian age. Following a brief emergence at the close of the Bendian, the Atoka formation, the youngest Carboniferous formation in the Ouachitas, was deposited. These formations are described in detail, beginning with the oldest, the Arkansas novaculite.

### ARKANSAS NOVACULITE

*Distribution.*—The Arkansas novaculite is found mainly in the central portion of the Ouachita area, but there are exposures along

[16] E. O. Ulrich, *op. cit.*, p. 26.

[17] Hugh D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 50* (1929), p. 24.

[18] Sidney Powers, "Age of the Folding of the Oklahoma Mountains, the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma, and the Llano Burnet and Marathon Uplifts of Texas," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928).

[19] W. A. J. M. van Waterschoot van der Gracht, "The Permo-Carboniferous Orogeny in the South-Central United States," *Verh. der Kon. Akad. van Wetenschappen te Amsterdam*, Deel 27, No. 3 (1931).

the northern margin in Oklahoma, where it is brought to the surface by faulting. The narrow belts in the Potato Hills and Black Knob Ridge in Oklahoma are found along thrust planes. The partially equivalent unit known as the Woodford is found in irregular patches along the northwest margin of the region near Wesley, Ti, and Bengal. These patches are thought to be fensters. Since the outcrops are in highly folded and faulted areas, the dips are steep and excellent exposures may be observed.

*Thickness.*—The thickness of the Arkansas novaculite varies greatly in the Ouachita area. The maximum thickness observed for the middle and upper portions assigned to the Mississippian is approximately 650 feet, while the minimum is less than 100 feet.

*Lithologic character.*—The middle Arkansas novaculite is characterized by platy cherts and black humulithic shales. At several places in Arkansas, as well as at Black Knob Ridge in Grants Gap, Oklahoma, a conglomerate occurs at the base, consisting of rounded-to-subangular pebbles of chert, sand, and quartzite. The upper zone consists of variegated, massive-bedded calcareous cherts with intercalated thin beds of quartzitic and chalcedonic cherts.

The middle Arkansas novaculite is very fossiliferous in places. A great number of the conodonts have been described by Cooper.[20] The following fossils were collected by the late Sidney Powers at Caddo Gap, Arkansas, and identified by the writer.

*Sporangites huronensis*
*Prioniodus reversus* Ulrich and Bassler
*Prioniodus subtilis* Ulrich and Bassler
*Hindeodella longodens* Ulrich and Bassler
*Hindeodella recta* Ulrich and Bassler
*Polygnathus pennatulus* Ulrich and Bassler

The upper Arkansas novaculite is unfossiliferous.

*Age and correlation.*—The oldest Carboniferous rocks in the Ouachitas are known as the middle Arkansas novaculite and are correlated on paleontological evidence with the Woodford chert of Oklahoma. The upper portion, which carries no fossils, may be correlated in part with the Woodford or perhaps with the much younger Boone chert.

*Origin.*—The origin of the novaculite is a moot question among geologists and is not discussed in this paper. Suffice it to say that siliceous rocks characterize much of the lower Paleozoic section in the Ouachitas and must have had a similar origin, which persisted over a great period of geologic time.

[20] C. L. Cooper, "New Conodonts from the Woodford Formation of Oklahoma," *Jour. Pal.*, Vol. 5 (1931), pp. 230–43, Pl. 28.

### HOT SPRINGS SANDSTONE

After a period of long-continued erosion which followed the deposition of the Arkansas novaculite, the first major orogeny is manifested by the massive conglomerates occurring at the base of the Hot Springs sandstone. Thus the Bendian period in the Ouachitas began with the deposition of the Hot Springs sandstone.

*Distribution.*—The Hot Springs sandstone is exposed in and near the city of Hot Springs, Arkansas, and in the Zigzag Mountains.

*Thickness.*—The thickness of the Hot Springs sandstone varies from 85 to 200 feet. The basal conglomerate varies from 12 to 35 feet.

*Lithologic character.*—The Hot Springs sandstone consists of fine-to-medium, angular-to-subangular, tightly bonded, finely laminated quartz. Intercalations of thin conglomerates are observed in this sandstone. Near the top the sandstone gradually grades into dark shales. The conglomerate which occurs at the base of this sandstone is made up mostly of the general Ouachita facies and consists of rounded, subangular and angular masses of chert of different varieties. The predominating colors of the cherts are black, drab greenish, and purple, and some of them show secondary veins of silica.

*Age and correlation.*—The Hot Springs sandstone is not exposed in Oklahoma. However, the conglomerate which occurs at the base of this sandstone is correlated with the silicified chert and chert conglomerates in the Potato Hills and in McCurtain County, on the basis of lithologic similarity and stratigraphic position.

### STANLEY SHALE

The Stanley shale overlies conformably the Hot Springs sandstone in Arkansas. Due to the gradual transition the exact contact is difficult to define.

*Deposition.*—The great clastic series of the Stanley consists of ill-sorted materials which were washed from rapidly eroding highlands at the south into a genetically related, dominantly sinking geosyncline. Its outer edge definitely extended into an embayment in the vicinity of the present Ardmore basin. The highlands at the south consisted of crystalline and metamorphic rocks and along their slopes heavy vegetation must have flourished, as is evidenced by the profuse amount of carbonized material and wood fragments throughout the entire sequence.

In McCurtain County, Oklahoma, and Polk County, Arkansas, interesting evidence exists of volcanoes during early Stanley time. Sheets of tuff mark the centers of eruption.

*Distribution.*—The Stanley shale crops out in broad crescent

bands and irregular patches, elongate east and west, throughout most of the Ouachita area.

*Thickness.*—The thickness of this formation is undoubtedly exaggerated at most places by close folding and faulting, although this is difficult to demonstrate locally in the field. But such phenomena as local slickensides and visible crumpling within the Stanley itself suggest that compression of these strata has resulted in a series of minor "Decken," giving the effect of a thickened section. The amount of this thickening can not be exactly estimated, but might be as much as one-third or one-half. In the Atoka Quadrangle Taff[21] measured 6,100 feet of sediments. The geologic map of Arkansas shows 6,000 feet and Honess[22] gives 10,000 feet or more. The thicknesses as published are actual and care was taken to obtain measurements where thickening by crumpling would be least.

*Lithologic character.*—Just east of Atoka, Oklahoma, in the base of the Stanley shale, thin flint beds are intercalated in black bituminous shales and gray-greenish clay shales. This applies to the contact at most places west from Hot Springs, Arkansas. The gradation downward from shale into a sequence of intercalated flint and shale is common. The base of the Stanley is hard to determine at most places in the Ouachita region.

A feature of interest in the Stanley shale is the occurrence of tuffaceous beds and hydrothermal veins, which occur near the base. The main massive body of tuff has been named by Miser[23] the Hatton tuff lentil. These beds are succeeded by alternating beds of thin sandstones and indurated, fissile shales, gradually grading into predominating dark gray, and black and blue-greenish shales, all of which are characterized by cone-in-cone structure, which in some places occurs in large masses. This structure is of widespread distribution. Successively higher are massive grits,[24] silty shales, and clay shales, followed by 25 feet of black slates and hornstones. This latter zone occurs approximately in the middle of the formation, and is known as the Smithville chert lentil.[25] Above this member, alternating massive argillaceous grits, very fine subangular sandstones, some quartzitic grits, and shales occur. It is noteworthy that southern exposures of

[21] J. A. Taff, *U.S. Geol. Survey, Atoka Folio 79* (1902), p. 4.

[22] C. W. Honess, "Geology of Southern Le Flore and Northwestern McCurtain Counties, Oklahoma," *Oklahoma Geol. Survey Circ. 3* (1924), p. 6.

[23] Hugh D. Miser, "Mississippian Tuff in the Ouachita Mountain Region" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 31 (1920), pp. 125–26.

[24] The writer considers grit an extremely fine-textured sandstone.

[25] Hugh D. Miser and C. W. Honess, *op. cit.*, p. 11.

the Stanley shale show that the sandstone ledges increase in thickness and clasticity toward the south and finger out toward the north, evidencing a southern source.

It is interesting to observe that asphaltic and gilsonitic seams parallel to the bedding are common in the Stanley. It is suggested that these deposits were forced into the rocks, pushing them apart. Oil and gas production is noted at several points in this formation in the northwestern Ouachitas, production coming at a shallow depth in sandstones near exposures of thrust faults.

*Fauna.*—After many years of constant search for fossils, very frequently with the aid and always with the enthusiastic support of the late Sidney Powers, the writer found several fossil localities both in the Stanley shale and the Jackfork sandstone. The fauna of the Stanley shale and Jackfork sandstone will be described in another paper.

Following is a list of localities and fossils of the Stanley.

Center, SW. ¼, SW. ¼, Sec. 30, T. 3 N., R. 21 E., Potato Hills, Oklahoma, about 20 feet south of old slush pit of well drilled in 1922.
Greenish tan, sticky shale.

*Sherbonites* sp.[26]; *Hyperammina rugosa* Waters; *Pleurotomaria* sp. (badly preserved).

NE. cor., SE. ¼, SE. ¼, Sec. 18, T. 2 S., R. 14 E., 3 miles south of Redden, Oklahoma.
Greenish gray, soft, flaky shale.

*Multidentodus* sp.; *Fenestella* sp.; *Healdia* sp.

NE. ¼, NE. ¼, Sec. 7, T. 2 S., R. 12 E., 2 miles east of Atoka, Oklahoma.
Dark gray splintery and conchoidal shale.

Cusp belonging to *Distacodidae; Sherbonites; Hyperammina clavatula* Howchin.

SE. ¼, SW. ¼, NW. ¼, Sec. 3, T. 4 S., R. 21 E., Oklahoma.
Gray-to-greenish, soft, flaky, sticky shale.

*Cystodyctia* cf. *elegans* Harlton (badly preserved); *Hypermammina rugosa* Waters; *Sherbonites; Spirillina bendensis* Harlton; *Rhombopora* sp. (badly preserved).

Further faunal evidence was secured from wells drilled in the Ouachitas, all of which were commenced in the Stanley. Following is a list of wells, showing localities and the fossils which were found in them.

SE. ¼, SW. ¼, NW. ¼, Sec. 16, T. 3 N., R. 22 E., east of Talihina, Oklahoma. From a depth of 1,100–25 feet the following fossils were encountered in dark gray, splintery shale.

*Sherbonites; Hyperammina clavatula* Howchin; *Nodosinella glennensis* Harlton; *Distacodus* sp.

NW. ¼, NW. ¼, NE. ¼, Sec. 10, T. 2 S., R. 15 E., Oklahoma.
From a depth of 760–90 feet the following fossils were encountered in gray-greenish, flaky shale.

*Multidentodu* ssp.; *Jonesina* sp.

[26] S. W. Lowman, "A New Genus of Foraminifera from the Paleozoic," *Jour. Pal.* (in press).

*Age and correlation.*—According to the faunal evidence, the Stanley shale correlates with the basal Springer formation of the Ardmore basin.

### JACKFORK SANDSTONE

The clastic deltaic Jackfork sequence continued the depositional history of the underlying Stanley shale, being the final shallow deposition in the basin largely filled with Stanley shale. Additional evidence of a southern source is found in the presence of many small pebbles in southern outcrops of Jackfork of which pebbles became conspicuously absent toward the north.

During Jackfork time the embayment of the Ardmore basin also extended north and northeast of the Arbuckle Mountains where the sediments are represented by the Union Valley sandstone, grading upward into the silty Wapanucka shale. The Union Valley sandstone has been correlated with the subsurface "Cromwell" sandstone series.

*Distribution.*—The great mountain-forming Jackfork sandstone is exposed in broad bands alternating with the valley-forming Stanley formation. The Jackfork has been deformed by folding and faulting and at most places dips at high angles.

*Thickness.*—According to Miser and Purdue[27] the measured thickness of the Jackfork sandstone is between approximately 5,000 and 6,000 feet. At the type locality[28] in the Jackfork Mountains the total thickness is about 3,800 feet. Honess[29] calculated more than 12,000 feet for the upper Jackfork and Atoka formations.

*Lithologic character.*—This formation consists of fine-to-medium, subangular, tightly bonded sandstones, grits, argillaceous grits, and quartzitic sandstones in most of the Ouachitas. Near its southern limits the sandstones are fine-to-coarse-textured, gradually grading northward to finer sands and grits. A few thin beds of blue-greenish, dark gray and some black bituminous shales of varying texture are found. The contact between the Stanley and Jackfork is typically transitional and in some places difficult to determine.

The cinnabar deposits of southwestern Arkansas are found in the Jackfork sandstone and were formed as the result of mineralization after deformation of the rocks. Presumably they were formed in Upper Cretaceous time, when there were active volcanoes at the locality of the diamond mines near Murfreesboro.

[27] Hugh D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), p. 133.

[28] J. A. Taff, *U. S. Geol. Survey, Atoka Folio 79* (1902).

[29] C. W. Honess, *op. cit.*, p. 12.

*Fauna.*—Following is a list of localities and fossils.

SW. ¼, SW. ¼, SW. ¼, Sec. 35, T. 1 N., R. 19 E., along Highway 271, Oklahoma. Dark gray-to-black bituminous, conchoidal shale.

*Multidentodus* sp.; *Cornuspira semiconstrictus* (Waters); *Fenestella* sp.; *Hyperammina clavatula* Howchin.

Center NE. ¼, NE. ¼, Sec. 20, T. 1 S., R. 16 E., southwest of Johns Valley, Oklahoma.

Dark gray, flaky-to-splintery shale.

*Hyperammina clavatula* Howchin; *Hypocrepina bendensis* Harlton; *Nodosinella glennensis* Harlton; *Healdia caneyensis* Harlton; *Aechminella buchanani* Harlton.

*Age and correlation.*—In the Jackfork sandstone diagnostic middle and upper Springer fossils make their appearance.

### LOWER JOHNS VALLEY SHALE

The Johns Valley shale, which stratigraphically overlies the Jackfork sandstone, is the boulder-bearing bed about which has centered most of the discussion among geologists who have studied the Ouachita region.

There are apparently two boulder-bearing beds, one in the lowermost portion and one in the upper portion, with an intervening section of shale largely devoid of boulders. However, at no one locality are these two exposed together, and the principal distinction is based on the smaller accompanying pebbles and cobbles which characterize the upper zone. In addition, there is some suggestion that the fossils in the Johns Valley shale at the type locality are somewhat older than those contained in that shale at Lamberson Spur and Compton railway cut.

*Distribution.*—The type locality of the Johns Valley shale is in Twps. 1 N. to 1 S., R. 16 E., Pushmataha County, Oklahoma, where it occupies the floor of Johns Valley, and is surrounded by high sandstone hills. This valley is located near the summit of a gently "synclinal" mountain. This shale also crops out in long narrow belts along the flanks of Windingstair Mountain and farther north and west. Many of the belts parallel faults. The total east-west distribution is about 120 miles.

*Thickness.*—The thickness of the shale in Johns Valley is estimated to be about 300 feet. However, due to the peculiar arrangement of the beds and the folding and maceration in some cases, it is impossible to make a correct estimate, though the thickness at some places appears to be several hundred feet.

*Lithologic character.*—The Johns Valley shale consists of dark gray-to-black, bituminous, splintery and conchoidal shale, and when

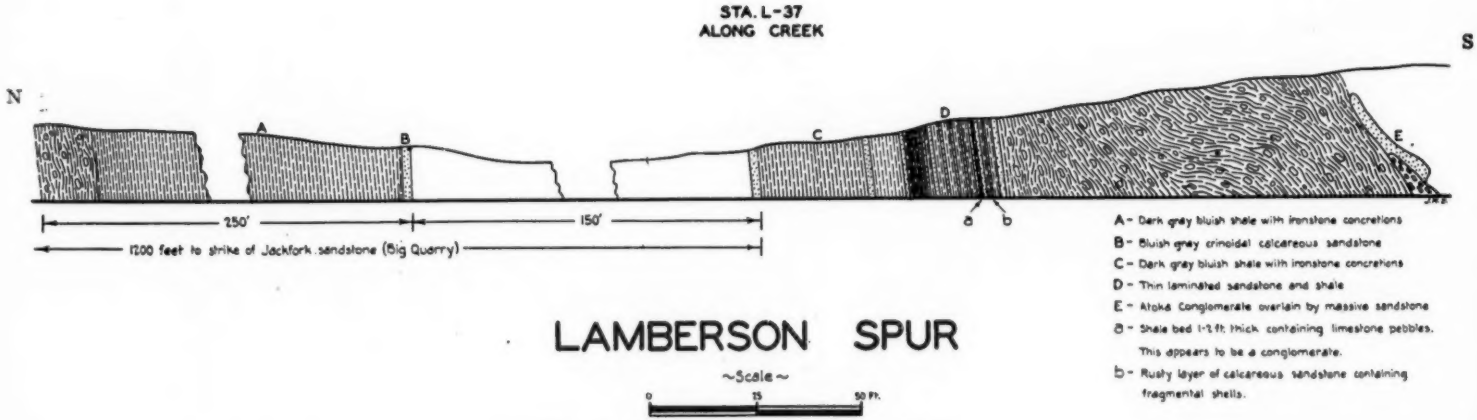


FIG. 5.—Geologic cross section of Lamberson Spur.

weathered it varies to drab-yellowish, in some places tan, flaky, poorly laminated, and sticky shale.

The most characteristic feature of this shale is the occurrence of exotics discordantly imbedded in the shale. Small and huge boulders, some of them gargantuan, are found, ranging in age from Canadian-Beekmantown of the Lower Ordovician to the Mississippian Caney. Regarding the origin and mode of the distribution of the exotics in this shale, it is deserving of note that their age varies greatly from place to place.

*Fauna.*—The fauna[30] of the Johns Valley shale is very interesting and has recently been described in part.

*Age and correlation.*—The lower Johns Valley shale is correlated with the middle Wapanucka of the Arbuckles, and the Kessler limestone of the Morrow formation of the Ozarks. In the Ardmore basin it is correlated with the Otterville to Jolliff limestones of the lower Dornick Hills formation.

### UPPER JOHNS VALLEY SHALE

*Distribution.*—The upper Johns Valley shale is exposed in Compton railway cut in Sec. 18, T. 4 N., R. 22 E., and at Lamberson Spur in Sec. 29, T. 4 N., R. 22 E.

*Thickness.*—The excellent exposures at the Compton railway cut (Figs. 4, 6, 7) are so intricately disturbed by folding and faulting that a complicated process of unravelling the structural pattern is needed to restore the picture of the original sedimentary sequence. The thickness is almost impossible to estimate, but might approximate 500 feet.

*Lithologic character.*—The main bulk of the upper Johns Valley shale is composed of medium-to-dark gray, bluish, semi-splintery-to-flaky, bouldery shale. A profuse amount of clay ironstone concretions characterize the shale. This bouldery shale is underlain by massive non-bouldery shale which contains intercalations of thin beds of sandstone, conglomeratic sand, and limestones. These were broken during crumpling and shearing of the beds, and the portions became more or less dissassociated, now giving the appearance of boulders. The sandstone beds in the non-bouldery shale at Compton railway cut may be described as follows.

> Light gray, slightly calcareous, quartzose sandstone, grains split through; dark brown, very fine calcareous sandstone, fretted with network of fine calcite veining, some of the layers cut by very fine seams of gilsonitic material; light gray, very calcareous sandstone with grains of glauconite and yellow sideritic oölites.

[30] Bruce H. Harlton, *op. cit.*

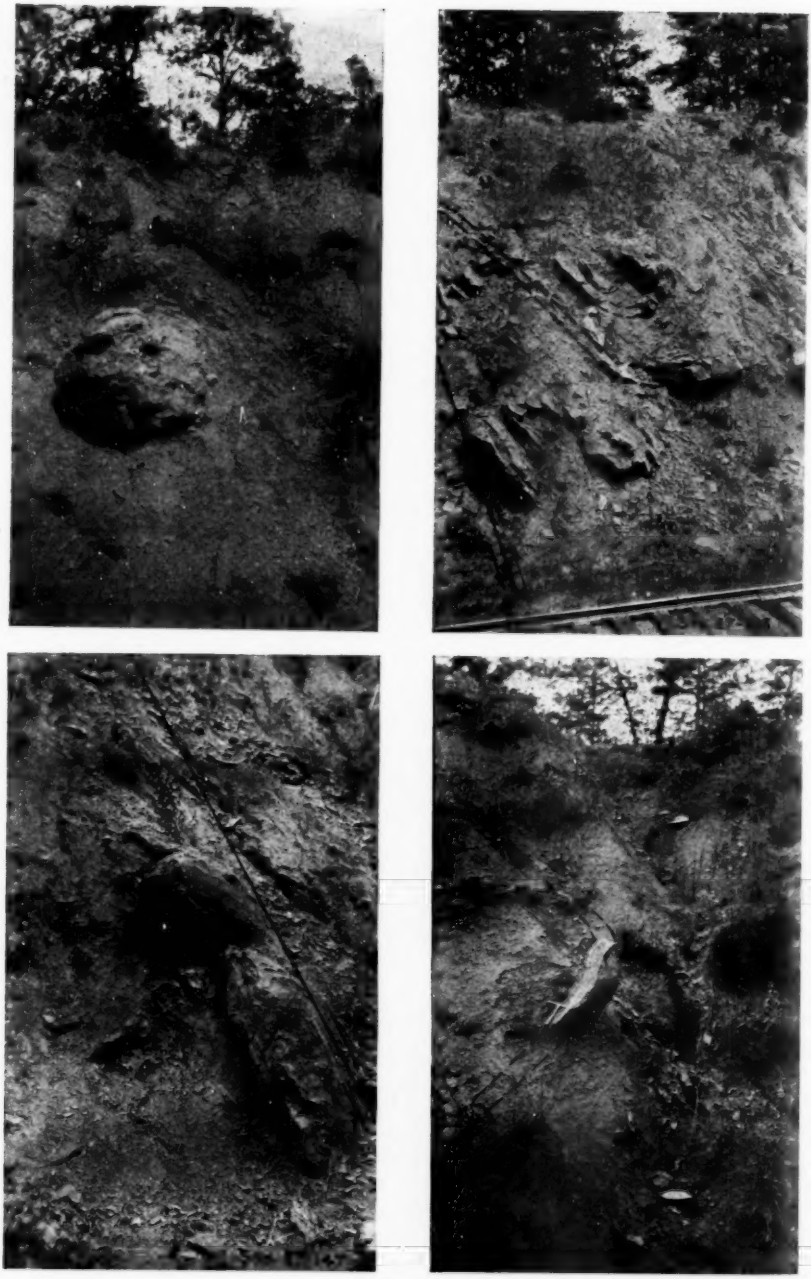

FIG. 6.—Photographs showing geologic conditions at Compton Cut.

*Sta. 87–68.*—Gray, calcareous sandy shale, grading into a hard, gray, argillaceous and calcareous, medium-grained subangular sandstone, with well rounded limestone pebbles at the base, the pebbles varying in size from 0.25 to 5 inches in diameter.

*Sta. 87–56.*—Most of the sandstones are typically interspersed with very coarse columnar calcite, similar to cone-in-cone structure.

The limestone conglomerates in this shale show very great variations and are described as follows.

*Sta. 87–31.*—The limestone conglomerate consists principally of brown, finely crystalline limestone, with large coarse crystals of brown resinous calcite, and a few rounded frosted sand grains, which break through on a fracture, also some included masses of finely crystalline pyrite, usually in lenticular form. There are several included fragments of light gray and green soft shale, which are also rounded to subangular in shape. The green shale is probably a metabentonite and resembles closely some of those found in the Simpson formation. There are also many rounded to subangular pebbles of cream colored, finely crystalline limestone and a few pebbles of dark gray chert. In some of the specimens the pebbles are set in soft gray shale matrix, the shale bending around the pebbles. The bond is very firm.

*Sta. 87–14.*—Light gray soft shale bond including many rounded frosted sand grains of varying size; small pyritic fragments and small pebbles of limestone thickly set, the limestone pebbles varying from white coarsely crystalline to brown, finely crystalline and crypto-crystalline. Some fine included fragments of light green shale, similar to those described from Sta. 87–31. Many included fine carbonaceous shreds and some plant remains. Much siderite.

*Sta. 87–55.*—Same as Sta. 87–31, but more arenaceous. Grains are rounded and frosted. Many brachiopod fragments.

*Sta. 87–77.*—Gray buff, sandy finely conglomeratic limestone; on a fresh surface the color varies to light brown due to the large amount of siderite present. The included sand grains are fine-to-coarse textured, rounded to subangular. The pebbles consist of dark gray calcareous shale including some rounded sand grains; some of the shale has a greenish cast. Some included fine grains of glauconite. The following fossils were found: *Macrochilina, Bellerophon, Pseudozygopleura, Chonetes, Paraparchites, Cystodictya, Rhombopora, Fenestella,* and *Lioclema.*

*Sta. 87–80.*—A dark gray, shaly calcareous matrix which varies to shaly limestone, including rounded frosted sand grains and blebs of green waxy shale resembling bentonite; including pebbles of limestone and dolomite mostly light gray, dense and crypto-crystalline; some fine included grains of glauconite; some dark gray quartzose pebbles with included crinoidal remains; sand is medium-to-coarse size, subangular-to-rounded and well bonded; thin tabular seams of gilsonite with associated hematite; also pebbles of light gray chert; some unidentifiable rhomboporoid bryozoans; some included pyrite and marcasite in irregular patches; some white calcite veinlets; fragments of finely crystalline limestone which become pink, yellow, and red due to weathering.

On the east side of the cut the conglomeratic limestones are similar to those at stations already described with the exception of Sta. 87–162, where an intraformational conglomerate is exposed, consisting of the following material.

Clay pebbles with siderite matrix containing many amphibian (?) vertebrate bones and numerous tree fragments. The edges of the pebbles are minutely irregular indicating that they did not suffer attrition or transportation. Many of the plant remains are represented by coal. The shale is very fragile.

As massive siderite is common in non-marine sands and clay shales containing coal, the evidence favors a terrestrial origin and probable formation in tidal flats.

The character of the exotic pebbles, cobbles, and boulders which are scattered throughout this massive shale is discussed under the heading, Boulders.

*Age and correlation.*—The shale at Compton Cut and Lamberson Spur is assigned to the upper portion of the Johns Valley shale and was probably deposited after the large exotics in Johns Valley and other places were laid down into the black mud which subsequently made up the shale.

The upper Johns Valley shale is correlated with the middle Dornick Hills formation in the Ardmore basin. Both are easily recognized by their strikingly interesting faunas. In the Ardmore basin the formations from the top of the Lester limestone to the top of the Otterville limestone are at present regarded as correlative with the lower Atoka formation. Investigation in the northern Arbuckle region has shown that typical Bendian beds have been mapped as lower Atoka. The writer includes these beds in the upper Wapanucka and correlates them with the middle Dornick Hills formation.

### BOULDERS

The essential conception concerning the history of the boulders is derived from observations made in Compton Cut and at Lamberson Spur, where the boulders are in place and the contacts well exposed.

The main massive body of bouldery shale, about 100–150 feet in thickness, contains exotics ranging from small pebbles of about 0.25 inch in diameter to boulders about 10 feet in thickness. These exotics are closely intermixed throughout the entire bulk of the shale.

A remarkable phenomenon is that the large boulders are usually surrounded by a fringe of pebbles, each pebble being separately imbedded in the shale except in a few rare cases. The thickness of the fringe is approximately 12 inches. The pebbles are well worn, polished, rounded-to-sub-rounded, a few subangular, and vary in size from cobbles several inches in diameter near the contact of the boulders to small pebbles near the outer edge of the zone. The character and age of the pebbles, cobbles and boulders vary greatly, and a few of the most interesting boulders will be discussed.

On the east side in Compton Cut (Sta. 87–100), a large well rounded boulder, polished, glossy, and of very coarse, tightly cemented conglomerate is exposed in this bouldery shale and may be described as follows.

Buff, tan, and light gray dense limestone; saccharoidal dolomite; sandy dolomite and fine-to-medium-rounded-to-subrounded dolomitic sandstone of upper Simpson (upper Black River) age; dense, birds-eye-like limestone of Chazyan age; black and drab gray-greenish and whitish chert of early Mississippian age; black Mississip-

FIG. 7.—Photographs showing geologic conditions at Compton Cut.

pian Caney shale with few altered phosphatic concretions; Mississippian Caney limestone concretions; black bituminous shale with round carbonaceous remains, resembling Woodford spores (*Sporangites*) in a different mode of preservation from Arbuckle Mountains type. Many strong calcite veinings extend through the cementing material, which is an impure calcareous bond and weathers to limonitic material. A large amount of hematitic bond was also observed.

This boulder is slickensided and grooved in different directions. The grooves and slickensiding undoubtedly were caused by abrasion from adjacent boulders during the crumpling and shearing of the shale at the time the rocks of the Ouachita region were greatly deformed by folding and faulting. The pebbles in the fringe surrounding this boulder are made up of the constituent parts of the afore-mentioned conglomerate and occur in two distinct shapes. The first are well rounded to sub-rounded, and suggest the effect of stream action; the others, also well worn and polished, are subangular and most of them have one side, or more, flattened. These pebbles show not only fractures, but also rotation of the segments between the fractures, exhibiting "minute faults." The relationship of the grooving and fracturing suggests that they are due to the same cause, namely, deformation by movements of the enclosing shale and its exotic boulders. Furthermore, a few of the flattened pebbles show faint parallel striations which have been produced by slickensiding. On one side near the base of this boulder the dark shale grades into maroon shale, whose color probably is due to weathering. The following Upper Bendian fossils were found in the shale immediately in contact with the fringe of pebbles.

*Orobias* sp.
*Hyperammina clavatula* Howchin
*Endothyra bowmani* Phillis
*Bythocypris tomlinsoni* Harlton
*Bairdia ardmorensis* Harlton

Of great importance is the fact that the conglomerate boulder represents two periods of generation; first, the deposition of the conglomerate itself and, later, the time of being torn off its exposure and carried away in the late Johns Valley depositing waters. The rounded-to-subangular masses as large as several feet across in the boulder were made probably by stream action. Furthermore, it shows a distinct though rough stratification with imperfect sorting. Some shale nodules with inclusions of shreds of highly carbonized material are present, all of which bear unmistakable evidence of deposition in water. There is of course a possibility that it may have originated in a talus slope.

To the casual observer this boulder may seem to be of the same age as the near-by exposed finely conglomeratic limestone in the shale, and may seem to represent a dislocated and much rounded portion of the interstratified conglomeratic limestone. However, the conspicuous difference in composition of the constituent masses of the boulder, in their much larger size, and the perfect roundness, polished and glossy character of the boulder itself, all suggest a different origin.

Therefore it is evident that the boulder was dropped in the mud which subsequently made up the shale.

Immediately south of the conglomerate boulder a broken sandstone ledge is exposed in place (Sta. 87–124). This ledge became disassociated during crumpling and shearing of the beds, and now has the appearance of a boulder. It is noteworthy that this broken portion is also surrounded by well rounded pebbles of diverse pre-Bendian material.

The next boulder of interest is a fractured limestone boulder where the surrounding pebbles are of an entirely different nature. They are subangular-to-rounded, well worn and polished, and are made up of the following material.

> Gray coarsely crystalline dolomite of upper Black River age composed of interlocking rhombs; green shale nodules; soft hematitic argillite nodules; limonitic shale concretions; and greenish-gray slightly argillaceous, tightly bonded grits.

These subangular, well worn, polished pebbles also show the characteristic "minute faults."

Another boulder, about 10 by 3.5 feet, of gray, dense limestone of Black River age, is exposed on the west side of the same cut (Sta. 87–20), and is also surrounded by pebbles having the same variations in material and characteristic shapes as the boulder first described.

The multitude of smaller boulders, cobbles, and pebbles (Fig. 8) in the main consist of masses of Ordovician limestone and dolomite. Numerous chert boulders of Woodford age are present, and a few of them are in contact with a sandy layer which is firmly bonded to the boulders. This sandy layer does not consist of granulated fragments of the chert itself. A profuse amount of phosphatic nodules and many limestone concretions from the Caney shale are scattered throughout the entire bouldery shale. A few well worn *Goniatites* from the Caney also were found associated with the shale.

Many of the smaller boulders, cobbles, and pebbles show rotation of the segments between the fractures.

Miser[31] and the writer have never found any boulders of Wapanucka age anywhere in the Ouachitas. All the rocks containing such fossils obviously formed a portion of a bed whose component materials were laid down in Johns Valley time.

#### CONGLOMERATE AT BOLES, ARKANSAS

Very coarse conglomerate exposed near Boles, Arkansas, is located approximately 300 feet west of the center of the east line of the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 4, T. 1 N., R. 29 W., in a creek. It has been gener-

[31] Oral communication.

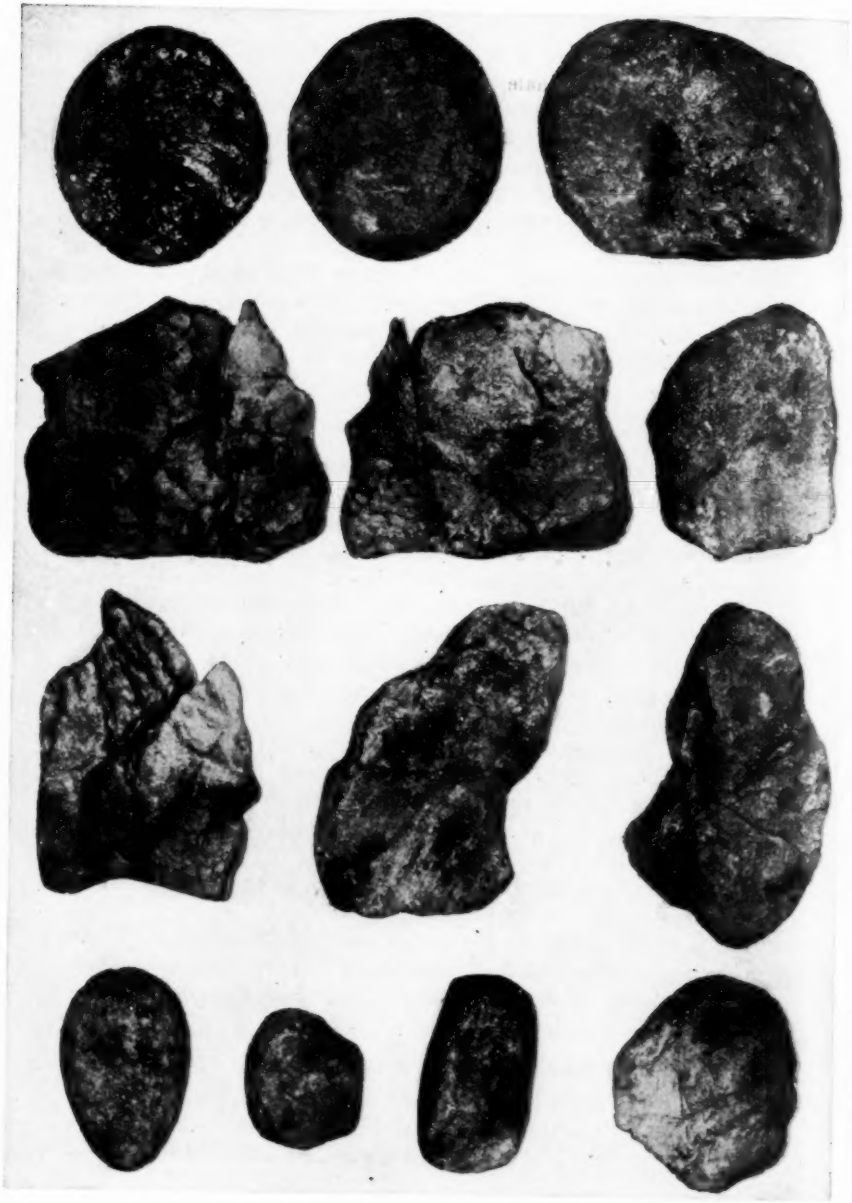

FIG. 8.—Pebbles from Compton Cut, natural size.

ally believed that this conglomerate belongs at the base of the Atoka formation. However, unquestionable paleontologic evidence determines it to be of early Bendian (basal Springer) age. The following fossils were found near the contact of the conglomerate with the overlying shale.

*Hyperammina rugosa* Waters
*Hyperammina clavatula* Howchin
*Multidentodus* sp.
*Sherbonites harltoni* Lowman
*Sherbonites ouachitensis* Lowman
*Sherbonites mammilatum* Lowman

The constituent masses of the conglomerate are subangular to subrounded and are composed of the following material.

Brown sandy limestone of upper Black River age; brown fine crystalline altered limonitic limestone; drab dense limestone with Black River ostracoda set in yellow, calcareous, ferruginous fine matrix including many rounded, frosted sand grains, pebbles of this limestone being irregular in shape; drab-grayish, dense limestone, also of upper Black River age; light gray, brownish crystalline dolomite with interlocking rhombs containing crinoids and *Rhynochotrema capax* of Fernvale age; many pebbles of finely crystalline limestone altered along edges to limonite; black bituminous shale of Caney age with masses of gray-to-black sucrose limestone, originating from limestone concretions in Caney.

A great amount of hematitic and limonitic bond was also observed. The bond is mostly calcium carbonate, in some instances highly ferruginous and sandy. Most of the sand grains are rounded and frosted, suggesting an Ordovician source. Weathering of the source rocks and the bond, which were originally highly ferruginous, has resulted in the occurrence of limonite in patches and splotches throughout the conglomerate. There are many small angular to subangular pebbles present in this conglomerate, suggesting a near-by source. This is further substantiated by the highly soluble nature of the limestone, which would have been removed or weathered if the source had been far distant. Much of the iron carbonate associated with the calcium carbonate has been altered to limonite. The elevation must have been high, as evidenced by the large masses in the conglomerate. The material itself is mostly lower Paleozoic limestone and sediments, indicating the source to be uplifted lower Paleozoic Arbuckle facies.

### ATOKA FORMATION

In considering diastrophic criteria of unconformity and changes of fauna the writer designates the conglomerate which occurs at the base of the Atoka near Stapp and Lamberson Spur, Oklahoma, as the initial deposit of the Pennsylvanian Des Moines group in the Ouachitas.

The origin of the Atoka formation is probably similar to that of the Jackfork, except that marine invasions were more conspicuous.

*Distribution.*—The outcrops of the Atoka formation occur in long, narrow bands in all parts of the Ouachitas.

*Thickness.*—Due to close folding and faulting the thickness of the Atoka formation is difficult to determine, and is estimated to be approximately 6,000–8,000 feet in Arkansas and Oklahoma, respectively. The contact of the Jackfork-Atoka formations is also very difficult of differentiation in some portions of the region.

*Lithologic character.*—The Atoka formation consists of friable and splintery shales, medium-to-dark gray with light greenish tints, weathering to yellow-tan. Intercalations of dark gritty shales and thin and massive, brown, fine-textured sandstones are common. Thin local conglomerates are noted throughout the formation. A chert conglomerate which occurs at the base is known as the Chickachoc chert lentil.

Two conglomeratic beds exposed south of Stapp, in the SW. ¼ of Sec. 7, T. 3 N., R. 26 E., were first described by Powers,[32] who stated that the boulders (masses) of black chert and Ordovician limestone in this conglomerate are rounded and tightly cemented.

Detailed examination of this conglomerate determines the masses as follows.

> Gray, brownish sandy limestone, sand grains rounded and frosted, matrix finely crystalline silty limestone; drab-gray fine, even crystalline limestone consisting of fine spherical calcite bodies closely set in matrix of sub-crystalline calcite, possibly oölites though no concentric structure is visible; gray limestone conglomerate, the pebbles consisting mainly of light and dark gray ferruginous limestone, matrix of fine quartz sand and finely crystalline calcite, numerous crinoidal remains, weathered surface shows subrounded depressions for the pebbles and a noticeably raised network for the bond. The smaller pebbles consist of: dark gray quartzose sandstone, grains are rounded, well sorted and largely of quartz, although some light green glauconite is present, bond siliceous, so that grains break through if a piece is chipped off; white coarsely crystalline limestone, typical Fernvale lithologic character, siliceous residue shows characteristic silicified brachiopods and some included sand; buff, dense limestone of upper Black River age; black bituminous shale.

*Fauna.*—Some of the megascopic fossils from the Atoka formation in south-central Oklahoma have been identified by Morgan.[33] A great number of the *Foraminifera* have been described by Galloway and Ryniker.[34]

*Age and correlation.*—The Atoka formation is correlated with the basal portion of the Des Moines group. In the Ardmore basin it is correlated with the upper Dornick Hills formation.

[32] Sidney Powers, *op. cit.*, p. 1043.

[33] George D. Morgan, "Geology of the Stonewall Quadrangle," *Bur. Geol. Bull. 2* (Norman, Oklahoma, 1924), pp. 64–65.

[34] J. J. Galloway and Charles Ryniker, "Foraminifera from the Atoka Formation of Oklahoma," *Oklahoma Geol. Survey Circ. 21* (1930).

ACKNOWLEDGMENT

For helpful criticism the writer is indebted to Hugh D. Miser and Walter H. Bucher. For discussion of various problems the writer wishes to thank John L. Ferguson, C. W. Tomlinson, and A. I. Levorsen. For detailed paleontological comparison of the fauna in the Ardmore basin the writer wishes to thank D. C. Nufer, who possesses one of the most splendid collections of the fauna in that area. Fanny C. Edson and Frederic A. Bush have given help by contributing information and collections. The illustrations were drawn by J. M. Dale.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 8 (AUGUST, 1934) PP. 1050-1058, 3 FIGS.

# CORRELATIONS OF PENNSYLVANIAN STRATA IN ARKANSAS AND OKLAHOMA COAL FIELDS[1]

T. A. HENDRICKS[2] AND C. B. READ[2]
Washington, D.C.

## ABSTRACT

Investigations in the Oklahoma and Arkansas coal fields have enabled the writers to establish definite correlations between the formations present in the two areas. These correlations differ considerably from those in current use, as will be pointed out in the following discussion.

In 1899, Taff published a report on the geology of the McAlester-Lehigh coal field of Oklahoma and defined the formations of the southeastern Oklahoma coal fields as now recognized. These are, from oldest to youngest, the Hartshorne sandstone, McAlester shale, Savanna sandstone, and Boggy shale. The Hartshorne sandstone in the McAlester-Lehigh field averages about 250 feet in thickness with a unit of shale in the middle part that contains the Lower Hartshorne coal. The McAlester shale in that field averages about 2,000 feet in thickness and is made up largely of dark marine shale that includes the Upper Hartshorne coal near the base and several sandstone beds and the McAlester coal in the middle portion. The Savanna sandstone averages about 1,200 feet in thickness, is made up of about equal amounts of sandstone and shale, and contains the Cavanal coal near the middle. The Boggy shale is about 2,850 feet thick, is made up largely of shale that contains many thin sandstone beds and that contains in the lower portion the Lower and Upper Witteville coals.

The formations of the McAlester district were traced eastward to the Arkansas state line by Taff and Adams. The locations of the formational boundaries near the state line, as shown on the map accompanying that report, agree very closely with the boundaries as mapped by the present writers in 1930 and 1931. The recent mapping by the writers of the formational boundaries and of all traceable units within the formations was done by plane-table traverses starting at the type localities of the formations and continuing eastward to the state line.

Investigations in the Oklahoma and Arkansas coal fields have enabled the writers to establish definite correlations between the formations present in the two areas. These correlations differ considerably from those in current use, as will be pointed out in the following discussion.

In 1899, Taff[3] published a report on the geology of the McAlester-Lehigh coal field of Oklahoma and defined the formations of the southeastern Oklahoma coal fields as now recognized. These are, from oldest to youngest, the Hartshorne sandstone, McAlester shale,

[1] Manuscript received, February 12, 1934. Read by title before the Association at the Dallas meeting, March 24, 1934. Published by permission of the director, United States Geological Survey.

[2] Assistant geologist, United States Geological Survey. Introduced by Hugh D. Miser.

[3] J. A. Taff, "Geology of the McAlester-Lehigh Coal Field, Indian Territory," *U. S. Geol. Survey 19th Ann. Rept.*, Pt. 3 (1899), pp. 423–600.

Savanna sandstone, and Boggy shale. The Hartshorne sandstone in the McAlester-Lehigh field averages about 250 feet in thickness with a unit of shale in the middle part that contains the Lower Hartshorne coal. The McAlester shale in that field averages about 2,000 feet in thickness and is made up largely of dark marine shale that includes the Upper Hartshorne coal near the base and several sandstone beds and the McAlester coal in the middle portion. The Savanna sandstone averages about 1,200 feet in thickness, is made up of about equal amounts of sandstone and shale, and contains the Cavanal coal near the middle. The Boggy shale is about 2,850 feet thick, is made up

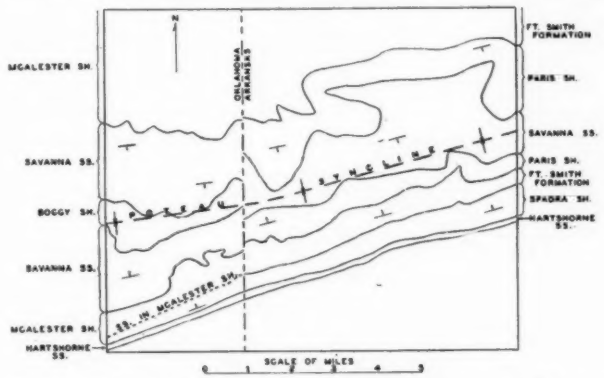


FIG. 1.—Adjacent portions of Poteau syncline in Arkansas and Oklahoma showing formation boundaries as mapped in each state.

largely of shale that contains many thin sandstone beds and that contains in the lower portion the Lower and Upper Witteville coals.

The formations of the McAlester district were traced eastward to the Arkansas state line by Taff and Adams.[4] The locations of the formational boundaries near the state line, as shown on the map accompanying that report, agree very closely with the boundaries as mapped by the present writers in 1930 and 1931. The recent mapping by the writers, of the formational boundaries and of all traceable units within the formations, was done by plane-table traverses starting at the type localities of the formations and continuing eastward to the state line.

In 1907, Collier[5] described the formations now recognized in the

[4] J. A. Taff and G. I. Adams, "Geology of the Eastern Choctaw Coal Field, Indian Territory," *U. S. Geol. Survey 21st Ann. Rept.*, Pt. 2 (1901), pp. 257–311.

[5] A. J. Collier, "The Arkansas Coal Field," *U. S. Geol. Survey Bull. 326* (1907), pp. 10–35.

Arkansas coal field. These are, from oldest to youngest, the Hartshorne sandstone, Spadra shale, Fort Smith formation, Paris shale, and Savanna sandstone.

The mapping of a portion of the Poteau syncline on each side of the state line between Arkansas and Oklahoma as shown in Figure 1 reveals the relations of the Arkansas to the Oklahoma units. The formation boundaries in the Arkansas portion of this map were taken from the geologic map of the Arkansas coal field prepared for the United States Geological Survey by A. J. Collier,[6] and the formation boundaries in Oklahoma were mapped by the writers.

The Hartshorne sandstone and the Savanna sandstone have been mapped in both Arkansas and Oklahoma. The Hartshorne sandstone is easily recognizable in both states. At Hartshorne, the type locality, the top of the formation lies above the Lower Hartshorne coal, which is also true at the east side of the Oklahoma coal field. However, as mapped in Arkansas (Fig. 2), the upper boundary of the formation is placed at the top of the sandstone that underlies the Lower Hartshorne coal, or 30–50 feet below the top of the formation as traced from the type locality.

In Oklahoma the McAlester shale lies between the Hartshorne and Savanna sandstones, and in Arkansas the Spadra shale, Fort Smith formation, and Paris shale are present successively from the top of the Hartshorne to the base of the Savanna. On the basis of that division of the strata into formations, the Spadra, Fort Smith, and Paris formations together are equivalent to the McAlester shale. However, the base of the Savanna sandstone as mapped in Arkansas (Fig. 1) coincides with the base of a sandstone in the upper part of the Savanna of Oklahoma. It is apparent, therefore, that the Spadra shale, Fort Smith formation, and Paris shale as mapped in Arkansas are equivalent to the upper 30–50 feet of the Hartshorne sandstone, the whole of the McAlester shale, and about the lower two-thirds of the Savanna sandstone of Oklahoma.

The Spadra shale (Figs. 1 and 2) is equivalent to the upper 30–50 feet of the Hartshorne sandstone and that portion of the McAlester shale below the sandstone that underlies the McAlester coal throughout the Oklahoma coal field. The Fort Smith formation includes those beds of the McAlester shale and Savanna sandstone that lie between the base of the sandstone that underlies the McAlester coal and the top of the lowest sandstone group of the Savanna. The Paris shale is equivalent to the portion of the Savanna sandstone of Oklahoma that

[6] A. J. Collier, *op. cit.*, map in pocket.

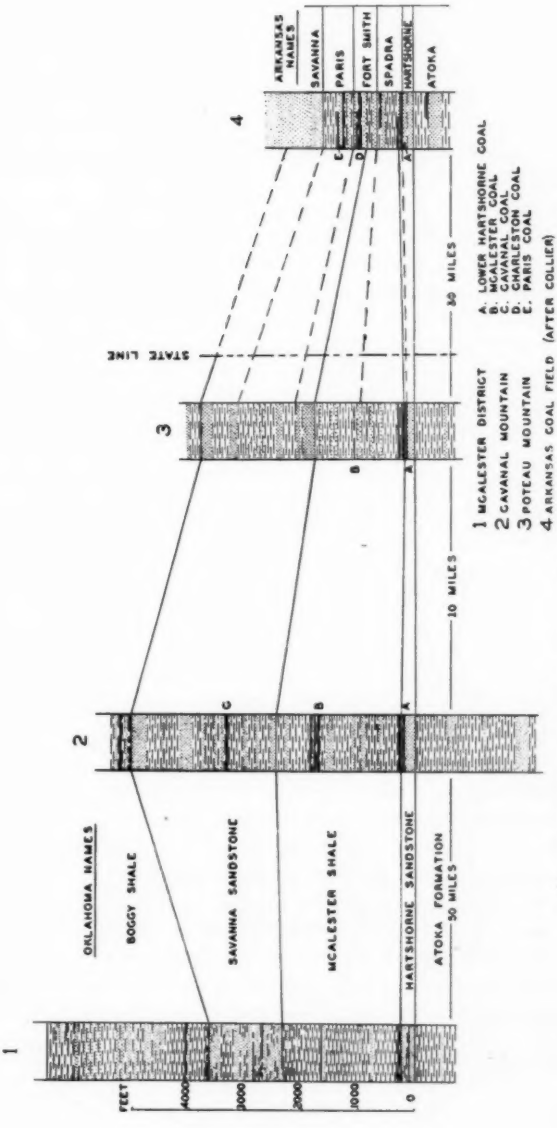


FIG. 2.—Generalized columnar sections of rocks in Arkansas and Oklahoma coal fields.

lies between the top of the lowest sandstone group and the base of the second sandstone from the top of the formation.

As has been pointed out, the base of the Savanna sandstone as mapped in Arkansas coincides with the base of the second sandstone below the top of the Savanna in Oklahoma. As shown in Figure 1, the Savanna of Arkansas includes only this upper portion of the Savanna sandstone of Oklahoma together with at least the lower part of the overlying Boggy shale.

This correlation based on the locations of the various formation boundaries at the Arkansas-Oklahoma state line, indicates that the beds in Arkansas that are equivalent to the McAlester shale are considerably thinner than the McAlester is in the adjoining portion of Oklahoma. This thinness of the McAlester shale in Arkansas accords with observations made by the writers in Oklahoma. Near Red Oak, Oklahoma, about 35 miles west of the Arkansas state line, the McAlester shale reaches its maximum known thickness, nearly 3,000 feet. South of Cavanal Mountain, about 15 miles west of the Arkansas state line, the McAlester is about 2,100 feet thick. At the west end of Poteau Mountain, about 6 miles west of the state line, the formation is about 1,280 feet thick. Thus it is apparent that the formation thins eastward from Red Oak to the Arkansas state line at the rate of about 60 feet per mile, and this thinning may reasonably be expected to continue into Arkansas, as is indicated by the correlations already given.

A study of the plant remains which are abundant at several horizons in both the Oklahoma and Arkansas coal measures has likewise furnished evidence bearing on the problem of correlation of strata in the two states. These floras were first studied by White[7] in an attempt to establish correlations with the Pennsylvanian sequence of the Appalachian trough. At that time the collections were too meager to permit a definite statement concerning accurate regional correlations. Since then the writers have made large collections throughout the Eastern Oklahoma coal field and have obtained several lots from Arkansas. These, supplemented by the old collections, have suggested certain correlations between Oklahoma and Arkansas, and the results which are here summarized[8] exactly corroborate the conclusions reached through stratigraphic studies.

[7] David White, *U. S. Geol. Survey 19th Ann. Rept.*, Pt. 3 (1899), pp. 457–534, Pls. 67–68.

David White, in A. J. Collier, David White, and G. H. Girty, "The Arkansas Coal Field," *U. S. Geol. Survey Bull. 326* (1907), pp. 24–31.

[8] A detailed descriptive paper bearing on the floras is now in preparation by Read and will be published later.

*Hartshorne sandstone zone of Linopteris gilkersonensis and Neuropteris capitata.*—The lowest horizon which the writers have been able to establish by paleontological means is at the base of the coal-bearing portion of the Pennsylvanian in both Oklahoma and Arkansas. The Hartshorne sandstone, which is the formation in question, contains one coal in its medial portion, and another occurs in the base of the overlying McAlester shale. Both of these coals can be traced over wide areas, the lower one being mined extensively in both Oklahoma and Arkansas, while the upper appears to be present only as far east as the Huntington, Arkansas, district[9] (Fig. 2). Numerous large collections have been secured from the lower coal and associated shales, and small lots have been secured from the roof of the upper coal, which is rarely fossiliferous. The composite flora thus obtained from both Arkansas and Oklahoma is a large one and is here listed.

*Sphenopteris mixta* cf. *stipulata*
*cristata*
*Pseudopecopteris obtusiloba*
*neuropteroides*
*macilenta*
*Mariopteris occidentalis*
*muricata*
*nervosa*
*Neuropteris scheuchzeri*
*rarinervis*
*harrisi*
*ovata*
*missouriensis*
*griffithi*
*capitata*
*Linopteris gilkersonensis*
*Pecopteris vestita* cf. *candolliana*
*oreopteridea*
*clintoni* cf. *arborescens*
*dentata*
*Callipteridium sullivantii*
*Alethopteris serlii*
*Desmopteris missouriensis*
*Odontopteris wortheni*
*Annularia stellata*
*sphenophylloides*
*Calamites suckowi*
*Calamodendron approximatum*
*Asterophyllites equisetaeformis*
*Sphenophyllum emarginatum*
*cuneifolium*
*suspectum*
*lescurianum*
*Lepidophyllum truncatum*
*Lepidocystis vesicularis*
*Rhabdocarpus multistriatus*

Owing to the extremely rapid deposition of the clastic sediments which comprise the bulk of the coal-bearing sequence (Hartshorne through Boggy) there is apparently only a very minor time interval involved, although the section totals some 6,000 feet. In consequence a large majority of Hartshorne species range through the entire succession of higher strata in the basin. From a careful analysis of the floras, however, it appears that *Linopteris gilkersonensis*, *Neuropteris capitata*, *N. rarinervis* (typica), *Sphenophyllum suspectum*, and *S. lescurianum* are widespread in occurrence in the interval from the base of the Hartshorne sandstone up to and including the roof shales of the Upper Hartshorne coal, but are not known from higher horizons in the region embraced by the basin.[10]

[9] A. J. Collier, *op. cit.*, p. 57.

[10] Concerning the age of the Hartshorne sandstone, McAlester shale, Savanna sandstone, and lower Boggy shale and their Arkansas equivalents, it is the opinion of

*McAlester coal—zone of Mariopteris sphenopteroides.*—In the McAlester Quadrangle and farther east in the Oklahoma coal field, the McAlester coal lies approximately 1,200 feet above the Hartshorne sandstone (Figs. 2 and 3). The roof of this coal contains a

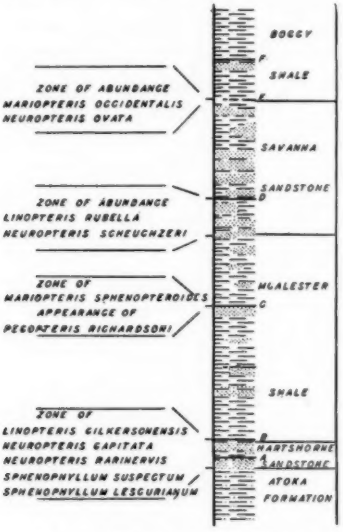


FIG. 3.—Floral zones in McAlester and eastern Oklahoma coal fields. *A*. Lower Hartshorne coal. *B*. Upper Hartshonre coal. *C*. McAlester coal. *D*. Cavanal coal. *E*. Lower Witteville coal. *F*. Upper Witteville coal.

Read that the entire sequence given above is basal Allegheny. This is exactly the conclusion arrived at by White (David White, *op. cit.*, 1899 and 1907), but since then the tendency has been to place the Hartshorne and even the McAlester in the upper Pottsville. As the purpose of this paper is not one of interregional correlation, and as this problem will be more fully treated in a subsequent publication, it is only necessary here to point out that while many species which occur in the Hartshorne and McAlester (as well as in the Savanna and Boggy) occur in the upper Pottsville, as the line is now drawn in such areas as West Virginia, Ohio, and Illinois, few if any of these fail to pass upward into indisputable Allegheny. On the other hand, the Hartshorne and succeeding formations carry species which are not known below the base of the Allegheny (*Neuropteris capitata*, *Pseudopecopteris macilenta*, *Neuropteris desorii*, et cetera). To draw the division line at the base of the McAlester shale would be unfortunate, as the Upper Hartshorne coal by definition is included in that unit and the roof of that coal carries a flora not easily separated from the flora of the Hartshorne formation. The flora of the McAlester coal is related closely to that of the Savanna and lower Boggy as well as to the Hartshorne. The obvious conclusion concerning these strata is that whatever may be their age it is undesirable to draw a major boundary within the sequence if this can be avoided. Available information favors a basal Allegheny (Clarion) age for the entire sequence here discussed, and the Pottsville-Allegheny division line should perhaps be drawn no higher than the top of the Atoka.

large flora, for the most part identical with that of the Hartshorne interval with the exception of those species which have been indicated as restricted to the latter. In addition, this coal marks the widespread occurrence of *Mariopteris sphenopteroides* and is the lowest horizon at which *Pecopteris richardsoni* occurs.

There is at present no paleontologic evidence concerning this horizon in Arkansas. According to Collier,[11] the Paris coal is the equivalent of the McAlester bed. Both stratigraphic and paleontologic data indicate that the Paris coal is higher in the section and that the McAlester coal is either represented by a thin coal in the lower Fort Smith or has disappeared entirely.

*Lower Savanna—zone of Linopteris rubella.*—At two localities in the McAlester Quadrangle a horizon near the base of the Savanna has yielded the following flora.

*Neuropteris missouriensis*
*scheuchzeri* (abundant)
*Linopteris rubella* (abundant)
*Pecopteris vestita*
*serpillifolia*
*Sphenophyllum emarginatum*
*Annularia sphenophylloides*
*Cordaianthus* sp.
*Sigillaria* sp.
*Stigmaria ficoides*

In the Cavanal syncline near Wister, Oklahoma, at a point slightly higher in the section (but still lower Savanna) a similar flora occurs. It will be noted that the critical feature of these floras is the abundance of *Linopteris rubella* and of *Neuropteris scheuchzeri*. In particular, the first-named species is important, as in Oklahoma it is apparently restricted to the interval between the base of the Savanna and the horizon of the Cavanal coal.

In Arkansas both the Charleston and the Paris coals contain in their roof shales a *Linopteris rubella-Neuropteris scheuchzeri* flora, and, as in Oklahoma, the flora is not known from either higher or lower horizons. There is thus a strong suggestion which when coupled with the stratigraphic evidence already presented affords nearly positive proof that the Charleston and Paris coals are of lower Savanna rather than McAlester age.

*Lower Witteville coal—zone of abundance of Mariopteris occidentalis and Neuropteris ovata.*—The base of the Boggy shale as it has been mapped in Oklahoma coincides with the horizon of the Lower Witteville coal. From this coal on Gaines Creek in the McAlester Quadrangle the following species have been identified.

[11] A. J. Collier, *U. S. Geol. Survey Bull. 326* (1907).

*Mariopteris occidentalis* (abundant)
*Pseudopecopteris* cf. *macilenta*
*Sphenopteris taffi?*
*Pecopteris dentata*
*richardsoni*
*unita*
*Asterotheca* sp.
*Neuropteris ovata* (abundant)
*scheuchzeri*
*desorii* (abundant)
*Sphenophyllum emarginatum*
*Annularia stellata*
*sphenophylloides*
*Asterophyllites equisetiformis*
*Calamostachys* sp.
*Lepidodendron lanceolatum*
*brittsii*
*Cordaites communis*
*Cordaianthus* sp.

Near Witteville, in the Cavanal syncline, the shales which lie immediately below the coal have yielded a similar flora with the essential features of *Neuropteris ovata* and *Mariopteris occidentalis* particularly striking. It must be remembered that this zone depends in its recognition on the abundance of the two species in question rather than their mere sporadic occurrence. The presence of *Neuropteris desorii* in the flora listed is likewise of interest, since this represents the lowest known occurrence of the species in the Oklahoma coal basin, and it may be further remarked that *N. desorii* is not recorded below the Kittaning coal group in the Appalachian trough.

Unfortunately there are no available collections from horizons above the Paris coal in Arkansas, so that it is impossible at present to draw upon paleontologic data for information concerning the equivalents of the Lower Witteville coal east of the Cavanal syncline. However, the stratigraphic relationships at the state line suggest that the horizon may be present in Arkansas.

## SUMMARY

The results of geologic and paleontologic investigations in the Oklahoma and Arkansas coal fields indicate that certain errors exist in current correlations of the coal-bearing strata (Pennsylvanian) in the two areas.

1. The Hartshorne sandstone (type locality in Oklahoma) has been mapped in Arkansas with the upper limit drawn 30–50 feet lower than in Oklahoma.

2. The McAlester shale (Oklahoma), which has been correlated with the sequence of Spadra shale, Fort Smith formation, and Paris shale (Arkansas), finds its more exact equivalent in the Spadra shale and the lower Fort Smith.

3. The upper Fort Smith and the Paris shale are thus Savanna in age, and it appears that a part of the so-called Savanna of Arkansas, as mapped, is basal Boggy.

4. In consequence the McAlester shale, heretofore regarded as maintaining a thickness of 1,500–3,000 feet in a large area in both Oklahoma and Arkansas, thins eastward from Red Oak, Oklahoma, at the rate of 60 feet per mile, with a resulting Arkansas section of McAlester (Spadra and lower Fort Smith) of 700 feet or less.

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VOL. 18, NO. 8 (AUGUST, 1934)) PP. 1059-1077, 5 FIGS.

# RELATION OF OUACHITA BELT OF PALEOZOIC ROCKS TO OIL AND GAS FIELDS OF MID-CONTINENT REGION[1]

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## ABSTRACT

The occurrence and distribution of much oil and gas in the Mid-Continent region have been influenced by the structural deformation of the belt of greatly deformed rocks of the Ouachita Mountain facies. They have also been influenced by the effect of the deformation of these rocks on the adjacent regions. Also, the structural history and character of the rocks on either side of the Ouachita belt are such that the belt separates areas yielding Cretaceous and Tertiary oil and gas on its gulfward side from areas of Paleozoic oil and gas northwest of it.

The belt of deformed rocks occupies a wide Paleozoic geosyncline, with arcuate bends, that is largely concealed beneath the Cretaceous and younger rocks of the Gulf Coastal Plain. The rocks of the geosynclinal belt are of Paleozoic age and their only exposures are in the Ouachita Mountains of Oklahoma and Arkansas and in the Solitario and Marathon regions of Texas. The Ouachita Mountains form the northernmost culmination of a great arc in the course of the geosyncline. Deep well data appear to indicate that the arc reaches from central Texas past the Ouachita Mountains and thence to southern Alabama. There is a significant parallelism between the course of this arc and the belts of outcrop of the Cretaceous and younger rocks in the Gulf region. The numerous masses of alkali-rich igneous rocks of Upper Cretaceous and early Tertiary age in and near the Gulf region are confined to the geosynclinal belt. They include many occurrences of serpentine which yields commercial oil along and near the Mexia fault zone in central Texas. This fault zone, which extends from Texas into Arkansas and Louisiana, is interpreted by the writer as marking the boundary that separates pre-Cambrian crystalline rocks of the Paleozoic land Llanoria from the Paleozoic rocks of the geosynclinal belt.

## GENERAL RELATIONS OF OUACHITA BELT TO OIL AND GAS FIELDS

At the Tulsa meeting of the Geological Society of America in December, 1931, F. H. Lahee displayed a map showing the course of the Ouachita belt of Paleozoic rocks across Arkansas, Oklahoma, and Texas, and also showing the oil and gas fields of the southern Mid-Continent region. The map was displayed as a lantern slide, but was not reproduced in the published paper.[3] This map suggested to the writer for the first time that the Ouachita belt of rocks bears a sig-

[1] Read before the Association at the Houston meeting, March 23, 1933. Manuscript received, April 11, 1934. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

[3] F. H. Lahee, "Contributions of Petroleum Geology to Pure Geology in the Southern Mid-Continent Area," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), pp. 953–64.

nificant geographic and geologic relation to the oil and gas fields of the Mid-Continent region.

The course of the Ouachita belt, as it has been described by several geologists, appears to extend from the Ouachita Mountains of Oklahoma in a southwesterly direction across Texas[4] and to extend from these mountains in Arkansas across Mississippi toward Alabama.[5]

All of the Ouachita belt, excepting the portion that is revealed in the Ouachita Mountains, is concealed underneath the Cretaceous and younger rocks of the Gulf Coastal Plain. The available information about the rocks in the concealed portions, obtained from deep well data,[6] indicates that they belong to the facies or sequence that is

[4] R. C. Moore, "Framework of Southeastern North America" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 181–82.

———, "Thicknesses and Characters of the Strata in the Deeper Sedimentary Basins of North America," in *Amer. Petrol. Inst., A Report on Fundamental Research in Petroleum, Pt. 1* (1932), p. 14.

M. G. Cheney, "Stratigraphic and Structural Studies in North-Central Texas," *Univ. Texas Bur. Econ. Geol. Bull. 2913* (April, 1929), p. 14.

———, "History of the Carboniferous Sediments of the Mid-Continent Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), p. 570.

E. H. Sellards, "Rocks Underlying Cretaceous in Balcones Fault Zone of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 819–27.

———, "The Pre-Cambrian and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), pp. 21–23, 67–140.

F. B. Plummer, "Pennsylvanian Sedimentation in Texas," *Illinois State Geol. Survey Bull. 60* (1931), pp. 262–65.

W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 991–1057.

———, *ibid., K. Aked. Wetensch. Amsterdam Vers., Afd. Natuurk., Deel 27, No. 3* (1931).

R. E. Rettger, "Interpretation of Grain of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 5 (May, 1932), pp. 486–90.

H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 801–18.

P. B. King, "An Outline of the Structural Geology of the United States," *Guidebook 28 International Geol. Cong. XVI Session, 1933*, pp. 15–20, and map (1932).

H. D. Miser, "Oklahoma Structural Salient of the Ouachita Mountains," *Jour. Washington Acad. Sci.*, Vol. 23 (1933), pp. 110–12.

———, "Some Problems of the Ouachita Mountains," *Tulsa Geol. Soc.* (1933).

H. X. Bay, "A study of Certain Pennsylvanian Conglomerates of Texas," *Univ. Texas Bull. 3201* (1931), pp. 182–86.

[5] R. C. Moore, *op. cit.*

W. A. J. M. van Waterschoot van der Gracht, *op. cit.*

P. B. King, *op. cit.*

H. D. Miser, *op. cit.*

———, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 50* (1929), p. 11.

W. H. Monroe, "Pre-Tertiary Rocks from Deep Wells at Jackson, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 1 (January, 1933), pp. 38–51.

[6] E. H. Sellards, "Rocks Underlying Cretaceous in Balcones Fault Zone of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 819–27.

found in the Ouachita Mountains. These rocks were formed in a geosynclinal trough formerly designated by the writer as the Ouachita geosyncline. Sellards[7] has recently applied the name Llanoria geosyncline to the portion of the trough extending from the Ouachita Mountains of Oklahoma to the Marathon-Solitario region of West Texas.

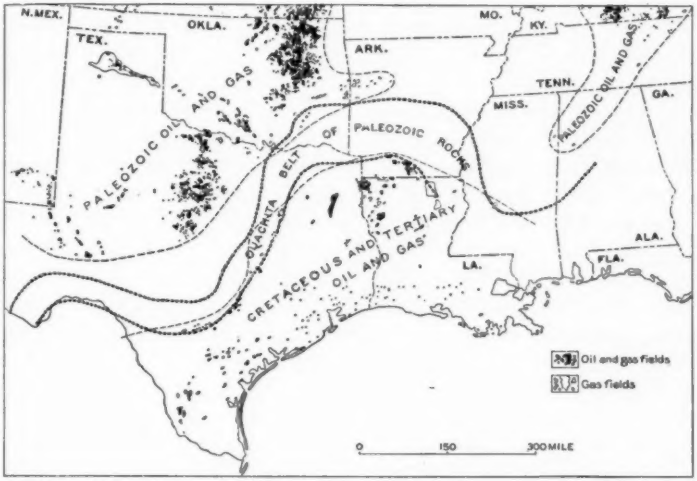


FIG. 1.—Map of southern Mid-Continent and adjacent areas showing relation of Ouachita belt of Paleozoic rocks to oil and gas fields.

The Cretaceous, Tertiary, and Quaternary deposits of the Coastal Plain have a regional gulfward dip that is interrupted at numerous places by faults, salt dome intrusions, and folds of small and large size, including domal uplifts. No wells have thus far been drilled sufficiently deep to reach the basement rocks southeast of the Ouachita belt, excepting in Caldwell County, Texas. All the oil production southeast of this belt therefore comes from Cretaceous and younger rocks.

The Ouachita belt occupies a significant geographic and geologic relation to the oil fields of the southern Mid-Continent region (Fig. 1).

H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *ibid.*, pp. 801–18.

[7] E. H. Sellards, "The Pre-Cambrian and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), pp. 23, 127–40.

Some of these relations are here briefly mentioned. The belt separates the areas yielding Cretaceous and Tertiary oil and gas on its gulfward side from areas of Paleozoic oil and gas northwest of it. Relatively few oil and gas fields have been found within the belt. There is, however, a long line of fields that follow its southern border. On the northwest side of the belt there are large productive areas of oil and gas in north-central Texas and southern, central, and northern Oklahoma. Paleozoic oil is not found adjacent to the belt, excepting along the northern border of Texas and in southern Oklahoma. The Arkansas Valley region adjoining the Ouachita region in eastern Oklahoma and western Arkansas contains many gas fields. These, as well as other relations, have resulted from the geologic history of the Mid-Continent region, including its paleogeography, conditions of sedimentation, and structural history—factors which, as has been stated by McCoy,[8] determine the type of sediments and the local structural features.

According to van der Gracht,[9] "The Paleozoic geology and paleogeography of the region are entirely controlled by a system of mountains which originated in the great world-wide Permo-Carboniferous orogenic cycle." These chains, including the Ouachitas, evidently determined the sedimentation, structure, and consequent accumulation of oil in the region. He continues,

> Not only is this true for the Paleozoic oil reservoirs, but it is probable that many of the important oil fields of the southern States, which occur in younger strata, ranging from the late Permian to the younger Tertiary, are structurally as well as genetically influenced by the general plan, and possibly, in some places, by petroliferous strata of the Paleozoic basement.

It is the writer's purpose to discuss very briefly the major structural and other geologic features of the Ouachita belt and the adjoining regions that bear on the oil and gas production of the Mid-Continent region. Because many hundreds of geologists have been and are still accumulating geologic data in the region, this task has been in large measure a matter of compilation of published information, particularly outside the Ouachita region to which the writer has devoted many years of study.

## MAJOR GEOLOGIC FEATURES OF OUACHITA MOUNTAINS

The exposed rocks in the Ouachita Mountains consist mostly of shale and sandstone, with some chert, novaculite, limestone, and tuff,

[8] A. W. McCoy, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), pp. 583–84.

[9] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), p. 992.

and are of many ages—Cambrian, Ordovician, Silurian, Devonian, Mississippian, and early Pennsylvanian (Pottsville). Their aggregate thickness is 25,000 feet. These rocks were laid down in a trough known as the Ouachita geosyncline. The Pennsylvanian rocks of Pottsville and Allegheny age of the Arkansas Valley, which adjoins the Ouachita Mountains, were laid down in the northern edge of the geosyncline, and if the thickness of the rocks of Allegheny age of the Arkansas Valley be added to the thickness of the older strata in the Ouachita Mountains, the total thickness of the strata in the geosyncline is about 30,000 feet.

The rocks of the Ouachita Mountain region were deformed by folding and faulting in late Pennsylvanian time and were compressed into a belt measuring about half its original width. Two major structural features are the Oklahoma and Little Rock salients (Fig. 2). The Oklahoma structural salient comprises the western portion of the mountains, and lies mostly in Oklahoma but partly in Arkansas. Its northern frontal margin, a great arc 180 miles in length, trends in a northeasterly and then easterly direction along the northern edge of the mountains in Oklahoma and then passes in a southeasterly direction across the mountains in western Arkansas. The Amity cross fault near Amity, Arkansas, along and near which the Arkansas cinnabar deposits are found, forms the margin of the salient at that locality. In Oklahoma the front of the salient is marked by thrust faults which bring together two different facies of rocks, the Ouachita Mountain facies and the Arbuckle Mountain facies. These two facies are brought together along the Ti Valley fault and along the portion of the Choctaw fault between Stringtown and Atoka, Oklahoma. The Ti Valley fault, in passing southwestward, joins the Choctaw fault at Stringtown. The deformation of the rocks in the salient was produced by compressive movements from the southeast and the frontal portion of the salient in Oklahoma appears to have been thrust northwestward a distance of 20 miles or more over the rocks of the Arbuckle Mountain facies. The salient is characterized by long, roughly concentric overthrust faults which bound northwestwardly thrust sheets. Toward the southwest the faults pass underneath the Cretaceous rocks of the Coastal Plain and their extent in this drection is thus not known, but toward the east the long faults found in Oklahoma die out near the Arkansas-Oklahoma line.

The rocks of that portion of the Ouachita Mountains east of the Oklahoma salient were deformed by movements from the south. Here the characteristic type of deformation is close folding, much of which is isoclinal.

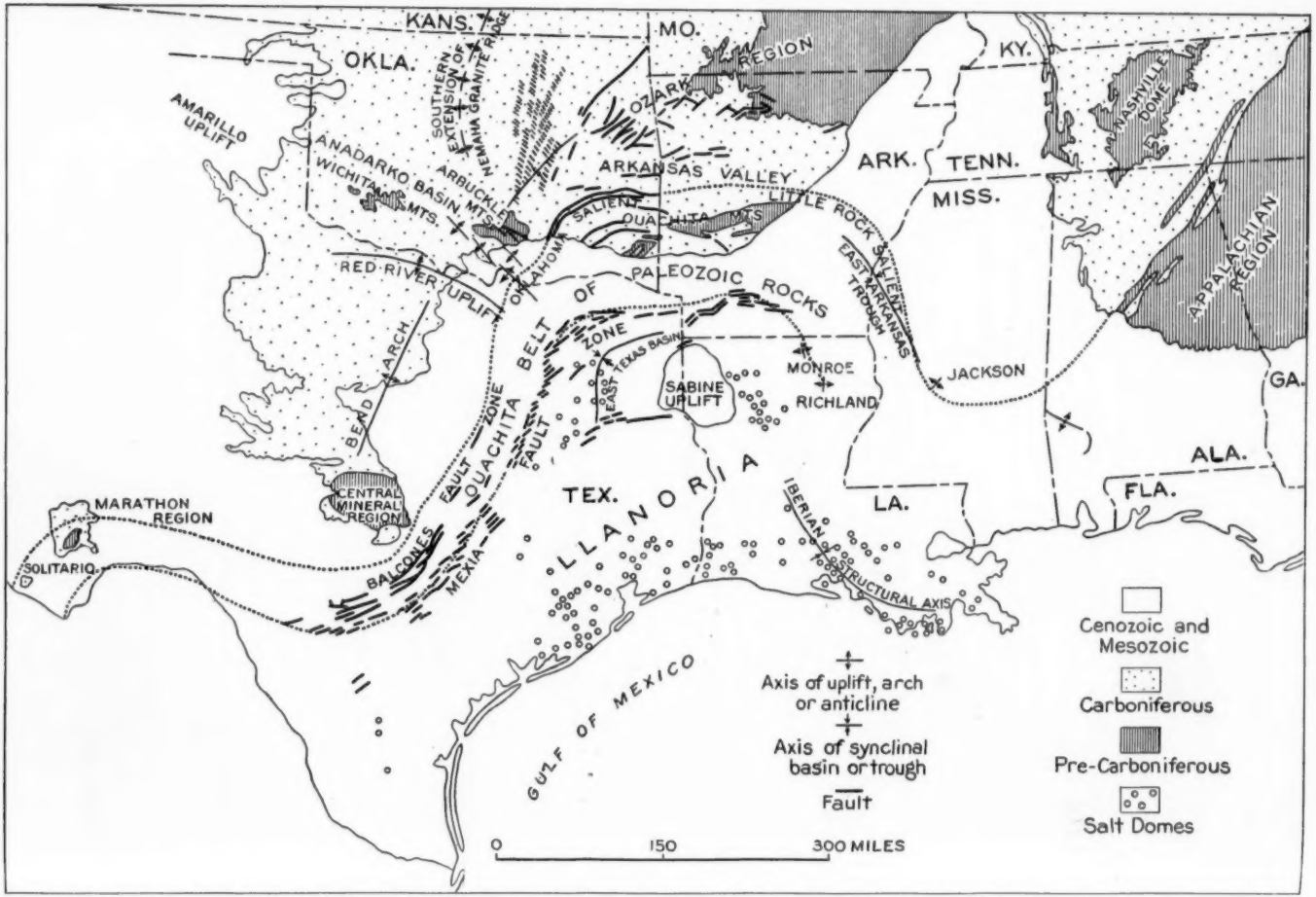


FIG. 2.—Geologic map of southern Mid-Continent and adjacent areas showing numerous structural features and showing their relation to Ouachita belt of

Most of the Little Rock salient at the east end of the mountains is concealed by the Cretaceous and younger deposits of the Gulf Coastal Plain. It includes the arcuately arranged structural trends in the region between Little Rock and Hot Springs. This salient resembles in form the Oklahoma salient.

### OIL EXPLORATION IN NORTHWEST PORTION OF OUACHITA MOUNTAINS

Exploration for oil in the northwestern part of the Ouachita Mountains has been carried on for many years, because of the presence there of occasional seeps[10] and deposits of grahamite.[11] Wells drilled near Weathers have found showings of oil and others in McGee Valley, in the vicinity of Redden, have found showings and small commercial yields. The wells have all been drilled in shale and sandstone of Carboniferous age.

The grahamite deposits and the oil wells are all found within a belt 20 miles wide, lying on the northwest margin of the Oklahoma structural salient, and extending from the west end of the Ouachita Mountains eastward for a short distance into Arkansas. The oil found in the wells, like that yielding the asphalt deposits, apparently did not originate in the Ouachita Mountain facies of rocks. It is believed by the writer, as well as by other geologists,[12] to have originated in deeply concealed rocks of the Arbuckle Mountain facies and to have migrated upward into the Ouachita Mountain facies. This part of the Oklahoma structural salient was presumably thrust a distance of 20 miles or more toward the northwest over the oil-bearing rocks of the Arbuckle Mountain facies.

A hypothesis that much of the Paleozoic oil and gas of Kansas and Oklahoma were distilled during orogenic movements in the deep Pennsylvanian geosynclinal basins, including the Ouachita trough, in southern Oklahoma, has been advanced by J. L. Rich.[13] From these

[10] Seeps observed by the writer are near Stringtown, Jumbo, Redden, and Weathers, Oklahoma.

[11] J. A. Taff, "Grahamite Deposits of Southeastern Oklahoma," *U. S. Geol. Survey Bull. 380* (1909), pp. 286–97.

[12] C. W. Honess, "Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties, Oklahoma," *Oklahoma Geol. Survey Bull. 40-R* (1927), pp. 26–27.

[13] John L. Rich, "Generation of Oil by Geologic Distillation during Mountain-Building," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 11 (November, 1927), pp. 1139–49.

———, "Function of Carrier Beds in Long Distance Migration of Oil," *ibid.*, Vol. 15, No. 8 (August, 1931), pp. 911–24.

———, "Source and Date of Accumulation of Oil in Granite Ridge Pools of Kansas and Oklahoma," *ibid.*, Vol. 15, No. 12 (December, 1931), pp. 1431–52.

———, "Distribution of Oil Pools in Kansas in Relation to Pre-Mississippian Structure and Areal Geology," *ibid.*, Vol. 17, No. 7 (July, 1933), pp. 793–815.

basins he believes the oil and gas traveled laterally through the porous rocks—the sand of the Simpson formation (Ordovician) and the weathered upper portion of the Arbuckle limestone (Cambrian and Ordovician)—to their present location. In this connection Rich[14] calls attention to the grahamite deposits in the Ouachita region and points out that they occupy fissures. Fissures such as those occupied by the grahamite would give opportunity for cross-bed migration into the carrier beds or out of them. Most authors[15] on the Mid-Continent region, however, hold the view that the Paleozoic oil and gas in the region did not move far from their original source into their present position in the Permian, Pennsylvanian, Mississippian, Devonian, and Ordovician rocks of the region.

### ARCUATE COURSE OF OUACHITA BELT

The course of the geosynclinal belt of the Ouachita Mountain facies extending southwestward from Oklahoma into Texas, past the east side of the Central Mineral region, and southeastward from Arkansas across Mississippi to southern Alabama, is a great arc. The Ouachita Mountains form the northern culmination of this arcuate belt that reaches from central Texas to Alabama.

This arcuate geosynclincal belt separates the Paleozoic land Llanoria on the south from rocks of a foreland facies on the north and northwest. The rocks of the foreland facies are, however, crossed by a wide geosynclinal belt passing in a southeasterly direction from the Texas Panhandle and meeting at right angles the Ouachita belt.

The northwest boundary of the Ouachita belt in Oklahoma is marked, as previously stated, by the Choctaw and Ti Valley faults, and is marked across much of Texas by an apparent southwest continuation of the Choctaw fault.

The southern boundary of the Ouachita belt is shown by wells[16] that have entered schist presumably of pre-Cambrian age in Caldwell County, Texas, and by an exposure in Mexico, near Boquillas, farther

[14] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), p. 916, and No. 12 (December, 1931), p. 1445.

[15] J. H. Gardner, W. B. Wilson, discussion of paper by J. L. Rich, "Source and Date of Accumulation of Oil in Granite Ridge Pools of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 12 (December, 1931), pp. 1448–52.

Fanny C. Edson, J. V. Howell, Anthony Folger, discussion of paper by J. L. Rich on "Distribution of Oil Pools in Kansas in Relation to Pre-Mississippian Structure and Areal Geology," *ibid.*, Vol. 17, No. 7 (July, 1933), pp. 808–12.

Sidney Powers, "Occurrence of Petroleum in North America," *Trans. Amer. Inst. Min. Met. Eng. General Volume* (1931), p. 495.

[16] E. H. Sellards, "The Pre-Paleozoic and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1932), pp. 45–47.

west.[17] Because this boundary coincides with the portion of the Mexia fault zone opposite the Central Mineral region, the suggestion is here offered that the Mexia zone may also mark the southern boundary of the Ouachita belt in northeastern Texas and in Arkansas. This fault zone is a curved zone extending from southwest Texas into Arkansas and thence eastward and southeastward toward Louisiana.[18] The zone contains not only faults but also folds that have provided favorable structural features for the accumulation of oil and gas. The Monroe and Richland domes of Louisiana appear to form a continuation of this zone of deformation.

### RELATION OF ORIGIN OF MEXIA AND BALCONES FAULT ZONES TO OUACHITA BELT

The Mexia zone presumably represents movement on lines of weakness in the basement rocks. Downwarping of the Coastal Plain in Tertiary time and the accompanying movements have produced the folds and faults in the Mexia zone and also have produced the faults in a zone farther west, known as the Balcones fault zone. Robinson[19] has expressed the opinion that the faults in both zones were produced by movements along zones of older buried faults in the basement rocks. A simiiar opinion concerning the Balcones zone has been expressed by Sellards, who points out that the zone falls within the belt of Paleozoic rocks of the Ouachita facies.[20] The faulting in these zones has been ascribed by Foley[21] to tensional stresses caused by subsidence in the Gulf Coastal Plain around the supporting positive element—the Central Mineral region. These stresses, as suggested by Stephenson,[22] were produced not simply by overloading and down-

[17] E. H. Sellards, *op. cit.*, p. 132.
———, "Rocks Underlying Cretaceous in Balcones Fault Zone of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), p. 820.
P. B. King, "The Geology of the Glass Mountains, Texas," *Univ. Texas Bull. 3038* (1930), p. 114.
Emil Böse, "Vestiges of an Ancient Continent in Northern Mexico," *Amer. Jour. Sci., 5th ser.*, Vol. 6 (1923), p. 133.

[18] Sidney Powers, "Occurrence of Petroleum in North America," *Trans. Amer. Inst. Min. Met. Eng., General Volume* (1931), p. 514.

F. H. Lahee, "Contributions of Petroleum Geology to Pure Geology in the Southern Mid-Continent Area," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), Fig. 2.

[19] F. J. Fohs and H. M. Robinson, "Structural and Stratigraphic Data of Northeast Texas Petroleum Area," *Econ. Geol.*, Vol. 18, No. 8 (1923), pp. 724–27.

[20] E. H. Sellards, "The Pre-Paleozoic and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1932), p. 139.

[21] L. L. Foley, "Mechanics of the Balcones and Mexia Faulting," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 12 (December, 1926), pp. 1261–69.

[22] L. W. Stephenson, "Structural Features of the Atlantic and Gulf Coastal Plain," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 896–97.

sinking of the Coastal Plain floor, but in addition by a positive upward movement in the portions of the Edwards Plateau and Central Mineral region adjacent to the Balcones fault zone. The east and south margins of the Edwards Plateau adjoining the Balcones zone are described by Cartwright[23] as having been downwarped at the time of the Balcones adjustment.

The southeastward downflexing along the portion of the Mexia zone in Texas is described by Lahee as having resulted in slight torsion movements that formed both the folds and faults.[24]

The trends of the individual faults, which vary from northeast to east, suggest a general southward to southeastward tilting of the portion of the Coastal Plain in Texas, southern Arkansas, and northern Louisiana. South of the Central Mineral region the general zone runs east, whereas the individual faults trend northeast. Southeast of the Central Mineral region the single faults lie parallel with the general zone, but in much of East Texas the zone extends north-northeast, whereas most of the single faults trend northeast. North of the Sabine uplift the faults seem to lie parallel with the general zone, whose course is somewhat irregular. Northeast of this uplift the main zone runs southeast, whereas the single faults extend east or east-southeast.

The Mexia and Balcones fault zones, and similar zones in Mexico, parallel roughly the perimeter of the Gulf Coastal Plain and seem, as pointed out by Stephenson,[25] to be related definitely to the great geosynclinal basin of the Gulf of Mexico. The numerous surface fractures in south Texas, recently described by Barton,[26] appear to be related in origin to the fault zones just mentioned, as well as other structural features of the Coastal Plain.

The relation of these fault zones to the perimeter of the Gulf Coastal Plain suggests, therefore, that the structural history of the Gulf Coastal Plain is related to the collapse and great subsidence of the Paleozoic land Llanoria and of the adjoining belt of Ouachita rocks. The amount of this subsidence in the coastal portion of Louisiana has been at least 5 miles, as is indicated by the thickness of 27,700

[23] Lon D. Cartwright, Jr., "Regional Structure of Cretaceous on Edwards Plateau of Southwest Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 7 (July, 1932), pp. 691–700.

[24] F. H. Lahee, "Oil and Gas Fields of the Mexia and Tehuacana Fault Zones, Texas," *Structure of Typical American Oil Fields*, Vol. 1 (Amer. Assoc. Petrol. Geol., 1929), p. 357.

[25] L. W. Stephenson, "Structural Features of the Atlantic and Gulf Coastal Plain," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 896–99.

[26] D. C. Barton, "Surface Fracture System of South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (October, 1933), pp. 1194–1212.

feet assigned by Howe and Moresi[27] to the Cretaceous, Tertiary, and Quaternary sediments in that part of the state. On geologic and geophysical data a sedimentary geosyncline is postulated by Barton, Ritz, and Hickey,[28] to follow the coast of Texas and Louisiana. The depth to the basement in this geosyncline is estimated by them to range from "20,000+ feet in the Houston district to 30,000+ feet in the area south of New Orleans."

### RELATION OF OUACHITA BELT TO CRETACEOUS AND YOUNGER ROCKS OF COASTAL PLAIN

The arcuate belt of Ouachita rocks parallels in a striking manner the belts of the Cretaceous and younger rocks between central Texas and Alabama (Fig. 3). This is true particularly of the distribution of the Lower Cretaceous (Comanche), whose northern boundary runs northeastward from central Texas and thence eastward and southeastward across Oklahoma and Arkansas to Mississippi.

The strand line of the Comanche sea in Trinity time, according to W. C. Spooner,[29] was limited at times in Arkansas and Louisiana by a profound flexure of the basement floor upon which the Comanche sediments accumulated. The flexure, which seems to follow the tectonic lines of the Ouachita belt, extends from southern Little River County, Arkansas, eastward to Calhoun County, Arkansas, and thence southeastward into Louisiana.

The salt domes—both the Interior and the Coastal domes—all lie south of the northern margin of this Lower Cretaceous embayment. This relation seems to corroborate other available evidence for the hypothesis to which some geologists, including the writer, adhere, that a salt basin existed in the region in Lower Cretaceous (Trinity) time (Fig. 3). There is, however, no conclusive evidence for the assignment of a Cretaceous age to the salt, and many geologists hold to the hypothesis that the salt is Permian.

Between central Texas and southwestern Arkansas the outcrop belts of the Upper Cretaceous and basal Tertiary rocks form arcuate bands parallel both to the Lower Cretaceous and to the near-by portion of the Ouachita belt. But eastward from central Arkansas the belts of Upper Cretaceous and early Tertiary rocks lie in the Mississippi embayment, whose downwarping began during the Upper

[27] H. V. Howe and C. K. Moresi, "Geology of Iberia Parish, Louisiana," *Louisiana State Dept. Conservation Geol. Bull. 1* (1931), pp. 86–92.

[28] D. C. Barton, C. H. Ritz, and Maude Hickey, "Gulf Coast Geosyncline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1446–58.

[29] W. C. Spooner, "Salt in Smackover Field, Union County, Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 601–10.

Cretaceous, and they are thus eccentric with reference to the near-by portion of the Ouachita geosyncline. In eastern and south-central Texas the base of the Tertiary follows both the Mexia fault zone and also the postulated southeastern margin of the Ouachita belt. Farther southeast in Texas and in Louisiana the belts of Tertiary and Quaternary rocks and even the coast line form arcs similar in pattern and position to the arcuate Ouachita belt of Paleozoic rocks, but they are more broadly curved than the Ouachita arc.

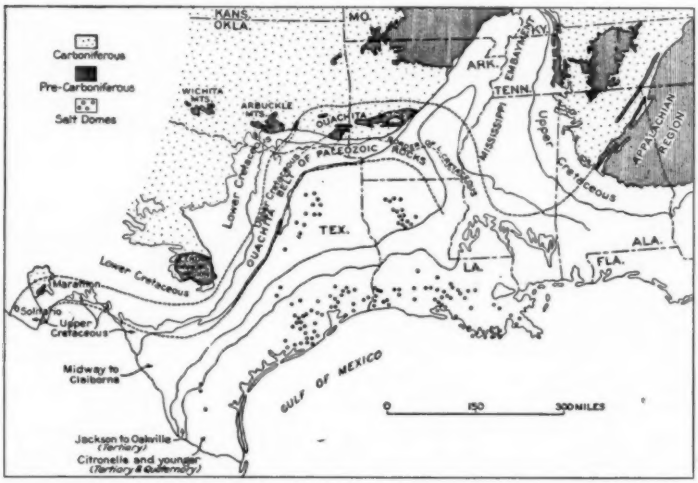


FIG. 3.—Geologic map of southern Mid-Continent and adjacent areas showing relation of Ouachita belt of Paleozoic rocks to outcrop belts of Cretaceous and younger rocks.

The coastal salt domes are found in a broad band along the coast. It is assumed by geologists generally that the upward intrusion of the salt was initiated by structural deformation of the salt-bearing rocks. Such deformation originated, perhaps, in the basement rocks. Since the coastal salt dome belt lies south of and roughly parallel with the Ouachita belt, it seems possible that the structural deformation responsible for the salt domes may have taken place along weak zones in the basement rocks in a manner somewhat similar to the movement that formed the Mexia and Balcones fault zones.

The inner border of the Gulf Coastal Plain follows approximately the course of the belt of deformed Paleozoic rocks from southern Alabama to southern Texas. The portion of the border of the Mississippi

embayment extending from central Arkansas to central Alabama represents the greatest divergence of the Gulf Coastal Plain border away from the belt of deformed Paleozoic rocks. Also, the Atlantic Coastal Plain[30] extending northeastward from Florida to Nova Scotia parallels approximately the Appalachian belt of deformation. It is thus seen that the Atlantic and Gulf Coastal Plains seem to follow belts of deformation from the Rio Grande past New England, a distance of 2,500 miles.

### IGNEOUS ROCKS OF CRETACEOUS AGE IN OUACHITA BELT

The igneous rocks in the Cretaceous formations of the Gulf Coastal Plain in Texas are confined to a belt 200 miles long that, as pointed out by Sellards,[31] coincides with the belt of folded Paleozoic rocks underneath the Cretaceous. Within this belt is the Balcones fault zone. The close correspondence of igneous activity and faulting in the Balcones zone show, as pointed out by Lonsdale[32] and Sellards,[33] that a genetic relation exists between them. The fields producing oil from serpentine fall within or near the Mexia fault zone that lies southeast of the Balcones zone. Also, igneous rocks in other places fall within or near the Ouachita belt of deformed rocks. These include the igneous rocks that are exposed in central Arkansas,[34] and those that have been reached in wells[35] in search of oil in southeastern Arkansas and the adjacent portions of Mississippi and Louisiana (Fig. 4).

[30] L. W. Stephenson, "Structural Features of the Atlantic and Gulf Coastal Plain," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 887–89.

[31] E. H. Sellards, "Oil Fields in Igneous Rocks in Coastal Plain of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 8 (August, 1932), pp. 741–68.
———, "The Pre-Paleozoic and Paleozoic Systems in Texas," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1932), pp. 137–39.

[32] J. T. Lonsdale, "Igneous Rocks of the Balcones Fault Region of Texas," *Univ. Texas Bull. 2744* (1927), p. 24.

[33] E. H. Sellards, *Univ. Texas Bull. 3232* (1932), pp. 137–39.

[34] G. C. Branner, *Geologic Map of Arkansas, Arkansas Geol. Survey* (1929).

[35] G. C. Branner, *op. cit.*
Ian Campbell and A. D. Miller, "Nepheline Basalt in the Richland Parish Gas Fields, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (October, 1928), pp. 985–93.
Watson H. Monroe, "Pre-Tertiary Rocks from Deep Wells at Jackson, Mississippi," *ibid.*, Vol. 17, No. 1 (January, 1933), pp. 38–51.
Noel H. Stearn, "A Geomagnetic Survey of the Bauxite Region in Central Arkansas," *Arkansas Geol. Survey Bull. 5* (1930), pp. 9–11.
M. N. Bramlette, "Volcanic Rocks in the Cretaceous of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (1924), pp. 344–46.
W. C. Spooner and H. W. Bell, "The Monroe Gas Field," *Louisiana Dept. Conservation Bull. 12* (1925), pp. 5–6, Figs. 1, 2.
H. D. Easton, *Oil and Gas Jour.* (March 24 and October 12, 1927).
Dugald Gordon, "Richland Gas Field, Richland Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), pp. 947–48.

All these igneous rocks are Upper Cretaceous in age, excepting some of the massive rocks in Texas to which Lonsdale[36] gives an early Tertiary age. They are all alkalic and there was not only an intrusion of dikes, sills, and stocks, but also volcanic activity whereby necks were formed and ash and tuff were ejected and deposited over wide areas in Upper Cretaceous time in Texas, southeastern Oklahoma, southern Arkansas, and northern Louisiana.[37] The igneous activity in early Upper Cretaceous time was contemporaneous with the initial downwarping of the Mississippi embayment, as well as downwarping

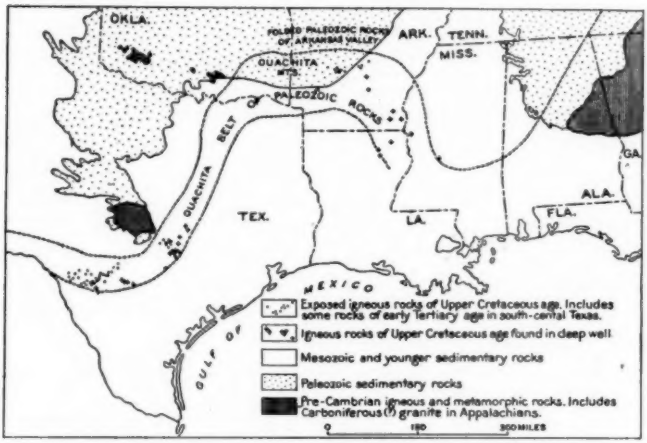


FIG. 4.—Geologic map of southern Mid-Continent and adjacent areas showing distribution of igneous rocks of Cretaceous age in relation to Ouachita belt of Paleozoic rocks.

elsewhere in the Gulf Coastal Plain, and, as has been stated by Moody,[38] it doubtless accompanied deep-seated adjustments in molten material under the subsiding area. The belt in which the alkali-rich rocks reached the surface apparently contained zones of structural weakness where the magma could move upward most readily.

[36] J. T. Lonsdale, *op. cit.*, pp. 44–46.

[37] C. S. Ross, H. D. Miser, and L. W. Stephenson, "Water-Laid Volcanic Rocks of Early Upper Cretaceous Age in Southwestern Arkansas, Southeastern Oklahoma, and Northeastern Texas," *U. S. Geol. Survey Prof. Paper 154* (1929), pp. 175–202.

[38] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), p. 551.

### SABINE UPLIFT

The Sabine uplift, on which there are many oil and gas fields, seems, as suggested by Powers,[39] to be a reflection in the Coastal Plain sediments of a positive element in the earth's crust. He also expressed the opinion that the uplift is underlain by pre-Cambrian rocks. The uplift lies opposite the Oklahoma structural salient of the Ouachita geosyncline in Oklahoma and northern Texas (Fig. 2). Because of these relations, the additional suggestion has been offered by the writer that the uplift is underlain by a batholith of Carboniferous granite that has intruded the pre-Cambrian crystalline rocks, just as granite batholiths of this age are shown by Keith[40] to lie opposite the three major salients in the Appalachian region.

Another explanation of the origin of the Sabine uplift offered by Moody[41] is that it is genetically related to the development of the ocean deep occupied by the waters of the Gulf of Mexico. According to this hypothesis, the lateral expulsion and deep-seated ejection into the adjacent continental mass of molten matter from a magmatic reservoir beneath the Gulf is responsible for the differential elevations in the region of the Sabine uplift in Tertiary time.

### ARKANSAS VALLEY AND JACKSON ANTICLINE

Gentle to moderate folds in Pennsylvanian shales and sandstones yield gas in the Arkansas Valley lying north of the Ouachita Mountains (Fig. 2). These folds were formed in response to the more intense deformation of the rocks in the adjoining Ouachita Mountains. It is the writer's opinion that the folded Carboniferous rocks found underneath the Cretaceous in the Jackson, Mississippi, gas field,[42] lie in a belt similar to the Arkansas Valley belt, and that Jackson, Mississippi, is thus north of the greatly deformed rocks of a southeastward extension of the Ouachita geosyncline. The Jackson anticline, as described by Monroe, has been produced by deformation above a plug of igneous rocks of Cretaceous age.

[39] Sidney Powers, "The Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 4, No. 2 (1920), pp. 117–36.

[40] Arthur Keith, "Outlines of Appalachian Structure," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), pp. 309–80.
———, "Structural Symmetry in North America," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 321–86.

[41] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 549–51.

[42] W. H. Monroe, "Pre-Tertiary Rocks from Deep Wells at Jackson, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 1 (January, 1933), pp. 38–51.

The trend of the East Arkansas trough[43] is southeast, parallel or nearly parallel with the supposed southeastward extension of the Ouachita geosyncline from Arkansas into Mississippi.

AREAS ADJOINING NORTHWEST SIDE OF OUACHITA BELT

The Ozark and Central Mineral regions are positive elements in the earth's crust (Fig. 2). They thus show a sequence of rocks of many ages, ranging from pre-Cambrian to Carboniferous and containing many unconformities.

Midway between the two regions there is a belt of mountains, uplifts, and folds—the Red River uplift, the Amarillo uplift, the Wichita and Arbuckle mountains, and the Criner Hills, all of which trend in a general southeast direction at right angles to the Ouachita geosyncline. These features are portions of a vast Carboniferous mountain range now largely buried by Pennsylvanian and Permian rocks. The geology of this belt is complicated by unconformities due to mountain-building that took place both early and late in the Pennsylvanian,[44] and that therefore took place during and after the deposition of the oil sands of Pennsylvanian age. The east end of this mountainous range lies buried beneath the northwestwardly thrust Oklahoma structural salient of the Ouachita geosyncline. The types of structure on which oil is found in this region are anticlines and buried hills.

A great arch extending from the Central Mineral region toward this mountain range is known as the Bend flexure. Another saddle-like arch extends from the Arbuckle Mountains to the Ozark region.

[43] C. L. Moody, *op. cit.*, pp. 531–51.
F. H. Lahee, "Contributions of Petroleum Geology to Pure Geology in the Southern Mid-Continent Area," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), Fig. 2.

[44] G. D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2*, Norman, Oklahoma, (1924), pp. 19–21.
Sidney Powers, "Age of the Folding of the Oklahoma Mountains—the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon Uplifts of Texas," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 1049–62.
———, "Occurrence of Petroleum in North America," *Trans. Amer. Inst. Min. Met. Eng., General Volume* (1931), p. 509.
C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 20–27, 47–51.
Victor Cotner and H. E. Crum, "Geology and Occurrence of Natural Gas in Amarillo District, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933), pp. 881–82.
Robert H. Dott, "Structural History of the Arbuckle Mountains," presidential address before the Tulsa Geological Society, January 9, 1933. Published by the oil department of the *Tulsa Daily World*.
———, "Structural History of the Arbuckle Mountains, Oklahoma," paper read before the International Geological Congress, Washington, D. C., July 29, 1933.
———, "Overturned Beds in Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 7 (July, 1933), pp. 865–68.
———, "Overthrusting in the Arbuckle Mountains, Oklahoma," *ibid.*, Vol. 18, No. 5 (May, 1934), pp. 567–602.

These arches contain much oil and gas whose accumulation into pools has been influenced by regional and local structural features and by lenticularity of sands. The formation of these arches was due to a southeastward tilting of their southeast flanks during the deposition on them of early Pennsylvanian sediments and to a later westward tilting of their west flanks.[45] Most of the sediments were derived from Llanoria. The eastward tilting of the east flanks of the two arches was accompanied by normal faulting in early Pennsylvanian time.[46]

The many lines of *en échelon* faults in central and north-central Oklahoma extend in a north-northeasterly direction. The lines lie parallel with the southern extension[47] of the Nemaha Granite ridge to the Oklahoma City field and also with the westernmost normal faults of the Ozark region. The faults themselves in the *en échelon* zones trend north-northwest. Fath,[48] as well as other geologists,[49] has postulated that the *en échelon* faults and the related folds are the result of horizontal and vertical movements along northward-trending fault zones in the pre-Cambrian basement rocks. Thom[50] has expressed the opinion that the northward movement on the east side of the fault zones resulted from a thrusting movement from the Ouachita Mountains. Also, Dott has expressed the opinion that the Ouachita thrusting set up a system of faulting in the saddle-like arch between the Ozark and Arbuckle regions.[51]

[45] A. I. Levorsen, "Convergence Studies in the Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 7 (July, 1927), p. 681.
M. G. Cheney, "History of the Carboniferous Sediments of the Mid-Continent Oil Field," *ibid.*, Vol. 13, No. 6 (June, 1929), p. 573.

[46] M. G. Cheney, "Stratigraphic and Structural Studies in North Central Texas," *Univ. Texas Bull. 2913* (April 1, 1929), p. 11.
A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (1928), p. 38.

[47] Sidney Powers, "Occurrence of Petroleum in North America," *Trans. Amer. Inst. Min. Met. Eng., General Volume* (1931), p. 509.
D. A. McGee and W. W. Clawson, Jr., "Geology and Development of Oklahoma City Field, Oklahoma County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 10 (October, 1932), p. 976.

[48] A. E. Fath, "The Origin of the Faults, Anticlines, and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128* (1921), pp. 75–84.

[49] L. L. Foley, "The Origin of the Faults in Creek and Osage Counties, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), pp. 293–300.
———, "Origin of Folding in Oklahoma," *ibid.*, Vol. 11, No. 6 (June, 1927), pp. 639–40.

[50] W. T. Thom, Jr., discussion of paper by L. L. Foley on "The Origin of the Faults in Creek and Osage Counties, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), p. 301.

[51] Robert H. Dott, "Notes on Pennsylvanian Paleogeography with Special Reference to South-Central Oklahoma," *Oklahoma Geol. Survey Bull. 40-J* (1927), pp. 16–22.

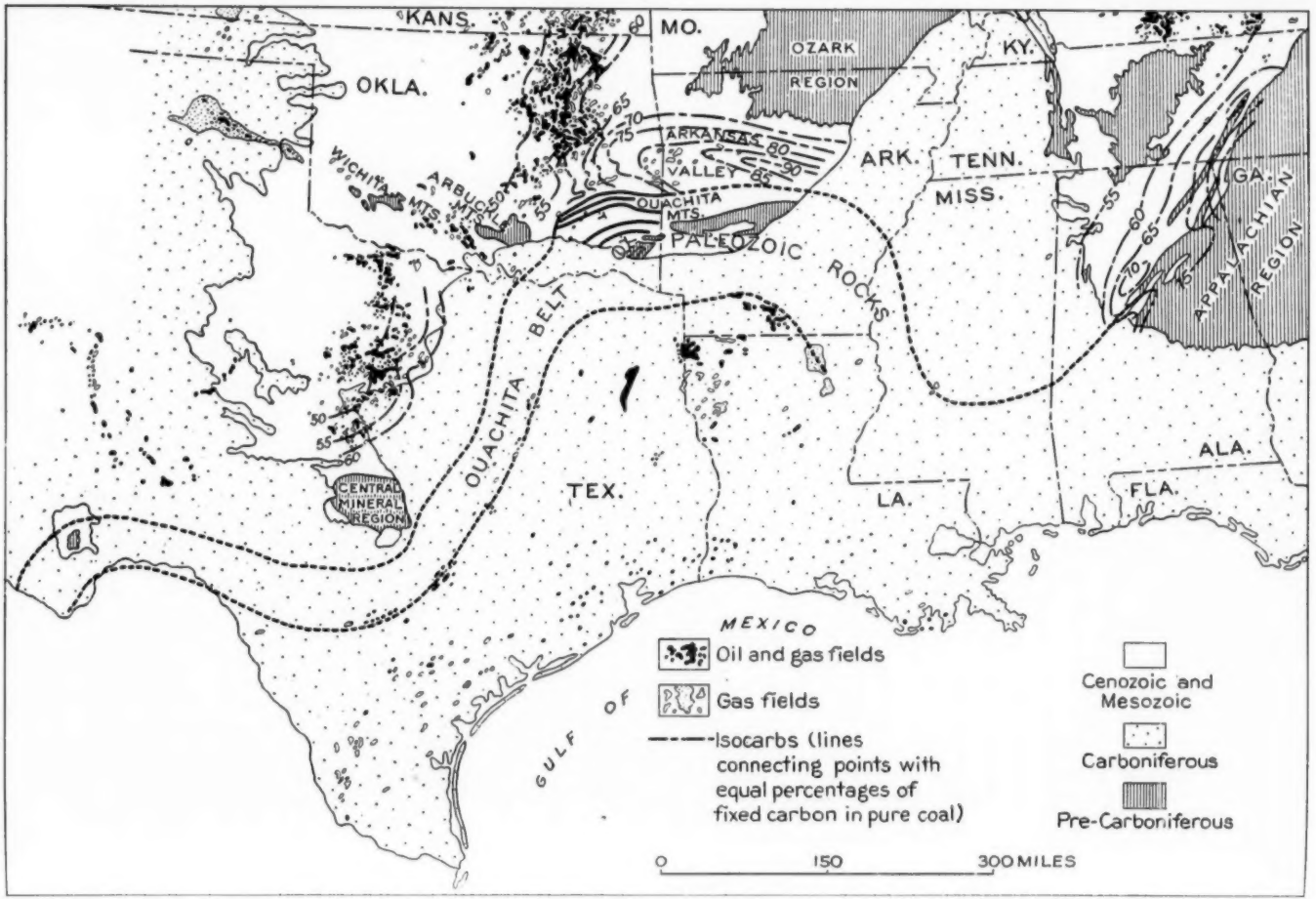


FIG. 5.—Geologic map of southern Mid-Continent and adjacent areas showing relation of metamorphism of Pennsylvanian coals to Ouachita belt of Paleozoic rocks and also to oil and gas fields.

RELATION OF COAL METAMORPHISM TO OIL AND GAS

There is a significant relation between the metamorphism of the Pennsylvanian coals and the distribution of the Paleozoic oil and gas in the Mid-Continent region. The accompanying map (Fig. 5) shows the oil and gas fields and the isocarbs for the Pennsylvanian coals. The isocarbs, which are lines connecting points with equal percentages of fixed carbon in pure coal, have been modified after White[52] for Tennessee, Semmes[53] for Alabama, Croneis[54] for Arkansas, and Fuller[55] for Texas and Oklahoma. From the map it is noted that the amount of fixed carbon increases southeastward toward both the Appalachian and Ouachita belts (Fig. 5). This is the direction in which the coals have in general been most metamorphosed as a result of the deformation of the rocks in these belts.

Most of the Paleozoic oil in Texas lies west of the 60 isocarb. Analyses of coal are not available for drawing the isocarbs from Texas into Oklahoma, for there is little or no coal in the belt of country lying between the Arbuckle Mountains and the Red River uplift and extending to and beyond the Amarillo uplift. The Choctaw fault marks the front of the Ouachita Mountains where the 55, 60, 65, 70, 75, and possibly the 80 isocarbs, approach and nearly reach the mountains from the north. The carbonization of the coal decreases westward along the fault coincident with the increase in the magnitude of the fault in this direction. Both oil and gas extend as far east as the 65 isocarb in Oklahoma, and gas alone extends to the east as far as the 85 isocarb in Arkansas. Showings and small commercial yields of oil are found in the northwest portion of the Ouachita Mountains in Oklahoma, and production of Paleozoic oil along the northern border of Texas is found as far east as the Ouachita belt. In these portions of Oklahoma and Texas the Oklahoma structural salient has been thrust toward the northwest, a distance of 20 miles or more, over the oil-bearing rocks of the Arbuckle Mountain facies of rocks.

[52] David White, "Some Relations in Origin between Coal and Petroleum," *Jour. Washington Acad. Sci.*, Vol. 5, No. 6 (March, 1915), pp. 189–212.

[53] D. R. Semmes, "Oil Possibilities in Northern Alabama," *Mining and Metallurgy*, No. 159, Sec. 5 (1920), pp. 1–10.
———, "Petroleum Possibilities of Alabama," Part 1, "Northern Alabama," *Alabama Geol. Survey Bull. 22* (1920), pp. 54–58.

[54] Carey Croneis, "Oil and Gas Possibilities in the Arkansas Ozarks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 3 (March, 1927), pp. 279–97.
———, "Geology of the Arkansas Paleozoic Area with Special Reference to Oil and Gas Possibilities," *Arkansas Geol. Survey Bull. 3* (1930), pp. 361–65.

[55] M. L. Fuller, "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," *Econ. Geol.*, Vol. 14, No. 7 (November, 1919), pp. 536–42.
———, "Carbon Ratios of Carboniferous Coals of Oklahoma and their Relation to Petroleum," *Econ. Geol.*, Vol. 15, No. 3 (April–May, 1920), pp. 225–35.

Fig. 5.—Geologic map of southern Mid-Continent and adjacent areas showing relation of metamorphism of Pennsylvanian coals and Paleozoic rocks and fields to oil and gas fields.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 8 (AUGUST, 1934), PP. 1078-1091, 1 FIG.

# DISCUSSION

## FACTORS GOVERNING ESTIMATION OF RECOVERABLE OIL RESERVES IN SAND FIELDS

This discussion refers to the article by O. L. Brace, published in the *Bulletin*, Vol. 18, No. 3 (March, 1934), pp. 343–57, and read at the Dallas meeting, March 23, 1934.

ALEXANDER DEUSSEN, Houston, Texas: I would like to ask Mr. Brace to give us instances of those fields which have been overestimated in the last few years.

O. L. BRACE, Houston, Texas: That is a rather large order because I hesitate to make specific statements about overestimation without presenting detailed data to support such statements and the time allotted me is not sufficient for this purpose. My claims for overestimation, however, apply to East Texas, Oklahoma City, Conroe, and possibly several others. To cite an example: when East Texas was in its infancy, 3 years ago, estimates of recoverable oil ran as high as, or higher than, 3 billion barrels. At that time, I published an estimate of 1.5 billion barrels, based on a study of reservoir conditions. At the present date, I find that numerous men, who have kept closely in touch with East Texas throughout its development, have revised their higher early figures downward toward this lower estimate.

I believe Oklahoma City has fallen far below the original estimations. I believe the original field estimates to have been 500–600 million barrels of recoverable oil. This has been cut down to a little more than half, or 350–400 million barrels. Some Oklahoma City man might say more about this.

ALEXANDER DEUSSEN: One further question: if at Conroe they use a factor of 700 barrels per acre on an average of 50 feet sand thickness, is it likewise an overestimation of the amount experienced in the Conroe field?

O. L. BRACE: In the past month or so, I have accumulated many sand data on the Conroe field. Based on an examination of approximately 200 sand logs, some of which, like those of the Sun Company, consist of completely cored sections with very high recovery and a group of Tidewater wells where a large part of the sand has been cored and recovered, I have concluded that an average of 50 feet of saturated sand of the character that Mr. Deussen describes, capable of 700 barrels per acre recovery, does not exist in the Conroe field. There is a large area in the heart of the field where the most favorable sands are occupied by gas, which fact tends to cut down the area in which thick, saturated sands are present. In studying these 200 sand records, I noted one well with recorded saturated sand thickness of 89 feet, the lower three-fourths of which was recorded by the drilling bit. A considerable number of additional logs of like character record 50–60 feet of saturated sand. One of the Sun Company wells, located very favorably on the west flank, actually recovered, according to their records, cored sands totaling 50 feet. As against such favorable records, however, dozens of wells show saturated sands ranging in total from a minimum of 8 feet to a maximum of 20 feet. To credit Conroe with an average of 50 feet of high-grade, saturated sand throughout the entire field is, in my opinion, much too high. This is in

disagreement with much of the accepted opinion but I am describing what I have seen of the records and not what someone has told me. I have never seen a complete section of pay sand removed from the Conroe field.

LEON J. PEPPERBERG, Dallas, Texas: I agree with what Mr. Brace said about the porosity of sands. I do not believe that a uniform porosity or permeability exists either vertically or horizontally for any great distances throughout any sand body. I believe we have sufficient real data to prove this positively and there are several good published papers on this subject. If you assume that an oil sand or an oil or gas reservoir is of uniform porosity or permeability, the remarks should be confined to the pay portion of the sand or formation. The statement that about 50 per cent or 25 per cent of a formation is made up of sand which has an effective porosity which will give up its oil as well as serve as a reservoir rock should be supported by a comment based on personal observation of real data showing how the percentage of "pay" in the known sand thickness was determined. C. V. Millikan[1] pointed out one practical method of accurately estimating the amount of "pay" in oil sands, where cores are not available. There is a great deal of difference between the "pay" and the sand thickness which is encountered in a well. More attention should be given to the determination of pay-sand thickness. Continuous research for many years has shown that in the Bradford sand body, which has been studied in more detail than any other oil sand, the percentage of porosity has a wide variation within a few inches vertically. This is a very important subject and should be given more serious consideration than it has received in the past. The term porosity should be confined to the percentage of voids in the rock. Effective porosity should be limited to the voids which not only act as oil, gas, and water reservoirs, but which are so continuously connected and consist of openings of sufficient size, that their contained fluids can be effectively drained, even at the minimum pressure to which the reservoir will be reduced during the economic life of the field. A high percentage of porosity (25–30 per cent) may be present in a rock, yet it may be practically impervious and consequently have no effective porosity. Permeability is not synonymous with porosity as so often loosely used. Permeability is "the volume of a fluid of unit viscosity passing through a unit cross section of the material under a unit pressure gradient in unit time."[2] For the same porous medium, fluid, and time unit the permeable factor is not constant if there is a change in temperature or pressure gradient. Mr. Brace has brought to attention a number of factors which should be considered when making estimates of reserves.

W. C. THOMPSON, Houston, Texas: It seems that Mr. Brace's paper and this discussion have brought out a very important point of which we should always take cognizance, namely, that the factors that we use are often not entirely known. Consequently, our results can not be exact.

If we find that in a certain field of a given number of acres the sand has a certain porosity and thickness we can easily estimate the original content, but in the last analysis we know only what the approximate porosity is for a

[1] *Petroleum Development and Technology* (Amer. Inst. Min. Met. Eng., 1925), pp. 183–95.

[2] R. D. Wyckoff, H. G. Botset, M. Muskat, and D. W. Reed, "Measurement of Permeability of Porous Media," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), p. 163.

given number of acres and the approximate sand thickness. Trying to obtain exact results from such data seems to me to be only glorified guesses, although this may sound unscientific.

Would it not be just as accurate to compare acre feet of an oil sand of the same age in the same region. We know about what the Mexia, Powell, and other fault-line fields have produced. It seems that by comparing sand thickness and other *known* factors some relative ideas of future production might be obtained.

I disagree with Mr. Brace when he says that most fields produce less than originally estimated. I do not know of many such cases.

O. L. BRACE: A great many estimates of reserves in the past have been guesses, not because of an absence of facts on which to base more logical conclusions, but because of a disregard of these facts. This paper was written in the hope of presenting methods by which a part, at least, of such guesswork might be eliminated. There is some merit in the suggestion of Mr. Thompson that estimations in new fields might be made by a comparison with old fields of similar type in which recovery is known. This scheme, however, presents one major difficulty. In the Mexia-Powell group of fault-line fields we know, for example, the yield per acre within fair limits of error. In this group of fields, however, we know very little about such important factors as thickness and character of sand, so that a direct comparison for making estimates of a field of the East Texas type would prove of little aid. As a matter of fact, the exaggerated early estimates on East Texas recovery were the product of this type of reasoning. It was assumed that because the Woodbine sand in the Mexia-Powell group yielded 25,000–30,000 barrels per acre, this sand should do likewise at East Texas. The basic fact was lost sight of that the reservoir rocks along the fault line are much thicker than on the eastern margin of the East Texas basin. I would say that, with the accumulation of reservoir data that is taking place to-day, the comparison method may prove very effective at some time in the future.

S. K. CLARK, Ponca City, Oklahoma: I heartily concur in some of the statements made in Mr. Brace's paper, particularly those in regard to the variability of sands and the impossibility of stating what percentage of recovery there has been of the total original oil content of any sand body. For that reason, I should like to say a word in favor of reducing production data to a more logical basis than that of acre yields.

There are certain facts regarding any oil reservoir which can be established within reasonable limits of accuracy. For the older fields, these include the depth, approximate thickness of "pay," and the total volume of oil actually recovered. For the younger fields, additional data regarding reservoir temperature and pressure, the amount of reservoir space occupied by "gas caps" and dissolved gases, and a considerable amount of porosity and permeability data are available.

A common practice in estimating the ultimate production of a new field is to compute the total volume of the oil-bearing portion of the reservoir rock and multiply it by a percentage of porosity and a percentage of recovery. A more logical method would be to estimate the recovery directly in terms of acre feet of reservoir rock on the basis of actual recoveries per acre foot in older fields, using the other known facts as modifying factors to be applied to the basic figures.

But very little work has been done toward reducing the tremendous mass of production data available to yields per unit of volume of reservoir rock. For the most part we have been content to figure acre yields without regard to thickness of "pay."

It is my thought that this Association could make a very great contribution to our knowledge of petroleum reserves by undertaking a coöperative study of the actual recoveries per acre foot of reservoir rock for the older fields throughout the country. With the production data reduced to a unit volume basis, we should have a foundation established on which studies of the effects of the various modifying factors could be based.

H. D. WILDE, JR., and T. V. MOORE, Houston, Texas (written discussion): Although we may take issue with some of the points raised in the paper, in general we agree with Mr. Brace and feel he has made an interesting contribution to this subject which, as he points out, was once a problem handled exclusively by the geologists but in present years has gradually passed to the petroleum engineer. However, is this not a problem upon which both the geologists and the engineers should coöperate rather than one to be worked out by either separately?

The author does well in calling attention to the fact that in volumetric calculations the shrinkage attending the production of oil should be considered as one of the factors. Tests have shown that a barrel of oil as measured at the surface ordinarily occupies 20–30 per cent greater volume when in the reservoir. In the past, there has been a tendency to neglect this factor, but, as Mr. Brace points out, it is better to consider it. Certainly it is highly important in the estimation of oil in place, but too-little is known of the subject to determine definitely the effect of this factor on recoverability.

The paper states that proration has fostered a tendency to over-estimate recoverable reserves. Has proration actually done this? Has not the orderly and more efficient production prevailing under proration increased the ultimate production obtainable from the fields? We can not agree with the author's statement that the ratio of total oil to recovered oil is substantially constant for all fields. There is good evidence that under orderly, efficient production methods, the ultimate recovery from some fields can be 50 per cent greater or even twice as great as the production that would be obtained under reckless competitive production. There is no question but that conservation of reservoir energy is of utmost importance in oil production, and that percentage recovery depends directly upon the efficiency with which gas and water are used.

The author's statement that fields with the porosity below 10–12 per cent will not yield their oil in commercial quantities is highly important, but is he not confusing porosity and permeability? Obviously, the porosity governs the total amount of oil in the rock but has little or nothing to do with the percentage of oil that will be produced, whereas the permeability is of vital importance. We agree with Mr. Brace that there is a limiting porosity or permeability below which sand will not yield oil in commercial quantities, and at present, we think that the limiting permeability is of the order of magnitude of 5 millidarcys.

We wonder whether the presence of moisture is as serious as the author claims. In obtaining core samples, especially by the rotary method, the core is brought into intimate contact with the drilling fluid containing water. It

is rather difficult to prevent the core samples from getting wet in this manner and the moisture found in the core on test may not be representative of that existing in the undisturbed oil sand. If the sands contain such large percentages of water along with the oil, why do not the wells produce water as well as oil?

It seems to us that the author belittles the effect of the water drive in producing oil. It is true that there are a number of fields in which the water drive is ineffective or absent, but in the past most fields with a potential water drive were developed in such a way that little benefit was obtained from the water drive. If properly controlled and utilized, the water drive can be of immense benefit in the production of oil. There is little doubt that in such fields as East Texas, Thompsons, and Sugarland, the water drive is playing a predominant part in the production of the oil and will be responsible for substantial increases in ultimate recovery if the present effective use of the water drive is continued.

O. L. BRACE: Some of the questions raised by Wilde and Moore require further consideration. I have made the statement that proration has fostered a tendency to overestimate recoverable reserves. My statement has reference to the psychological effects of proration and not to the physical. As to the physical effects, I am not at all sure that they are correct in their conclusion that orderly development greatly increases recovery. In instances where there is an excess of gas in the reservoir, it is probable that conservative development, accompanied by a full utilization of gas energy, will increase the quantity of flush oil, at least. In fields of the East Texas type, however, I am inclined to believe that close drilling and rapid extraction of oil will increase, rather than decrease, the quantity of recoverable oil. I am, of course, dealing purely with the physical side of the recovery problem in this paper and not with the economic side.

I must take issue with the assumptions contained in the statement of Wilde and Moore that "there is good evidence that under orderly, efficient production methods, recovery can be 50 per cent or even twice as great." In the records of the fields of the past, we have no exact knowledge as to the relationship of recovered oil to reservoir oil and it is, therefore, impossible to state that a field, under the modern method of operation, will experience a greatly enhanced recovery as compared to those under the old method.

Concerning the question of contained moisture, I am unable to improve on the explanation already offered as to why, if there is water present everywhere in the sand, wells do not produce this water along with the oil. In submitting this problem I have admitted the need for further consideration and study. It seems to me, however, that the conditions surrounding the cutting of such cores eliminate the possibility of contamination by drill water. During the process of cutting, the sand carries a pressure equal to that of the reservoir and the equalization of this pressure from the center of the core outward ordinarily continues for some time after the core has been extracted. Drill water could penetrate only with great difficulty under these circumstances. It is an additional factor of significance that the contained water is saline and not fresh.

To enter into a lengthy consideration of water drive would require more space than this discussion will permit. Wilde and Moore contend that, if properly controlled and utilized, the water drive can be of immense benefit,

presumably, although they do not specify, in increasing recovery. It is assumed that their qualifications have reference to orderly development and to the conservative production of oil. From my viewpoint, these are the conditions under which the beneficial functions of encroaching water will be least effective. In sand fields, the favorable action of water drive lies in its ability to flush the sand. The more rapid the extraction of oil, the greater the flushing action of the encroaching water. It would seem logical to assume, therefore, that under the rapid type of exploitation such as characterized the Mexia-Powell group of fields, water encroachment performed a much more beneficial function than will be the case in areas of more conservative operation such as Thompsons and Sugarland. I can see no present evidence that water is acting as a favorable agency in the East Texas field.

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## CORRECTION TO STRATIGRAPHY OF HOXBAR FORMATION, OKLAHOMA

On Plate XX of *Bulletin 46* of the Oklahoma Geological Survey,[1] broken lines indicate the supposed course (inferred from reconnaissance observations) of the outcrop of various resistant members of the Hoxbar formation from the vicinity of Ardmore southeastward to the type locality of the formation. Later, more complete mapping has revealed some errors in that map, particularly with respect to the lower members of the formation, which through a considerable portion of that distance are concealed by alluvium of the West Fork of Anadarche Creek and of tributaries thereto. A corrected map of the Hoxbar members south of Ardmore is submitted herewith (Fig. 1).

During 1932 and 1933 the Gypsy Oil Company and the Schermerhorn Oil Corporation coöperated in mapping the area in question in complete detail by plane table for future sampling of the Hoxbar and Deese formations, which are here developed in maximum thickness (approximately 11,000 feet in the aggregate) and occur in simple homoclinal position with few local structural complexities.

The principal reason for undertaking such detailed mapping at this time, in an area so nearly devoid of oil possibilities, was the plan then beginning to materialize for the construction of a dam 150 feet high near the southeast corner of Sec. 14, T.6 S., R.2 E., Love County, Oklahoma, across the gorge cut by Anadarche Creek through the Devil's Kitchen member of the Deese formation, which would impound about 10,000 acres of water, covering a large part of the area in question. This project was definitely espoused by the last legislature of Oklahoma, which appropriated $90,000.00 for the purchase of land in and bordering the proposed Murray Lake.

The geologic field work was done under direction of M. P. White and the writer, by W. Morris Guthrey and Charles A. Milner, who also prepared the final map on a scale of 800 feet to the inch. As the complete map measures 42×74 inches, it has not been practicable to publish it; but copies have been made available on request for use by other geologists, and a copy has been filed with C. E. Decker, curator of publications of the Oklahoma Geological Survey at the University of Oklahoma, at Norman. A similar map has been

[1] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929).

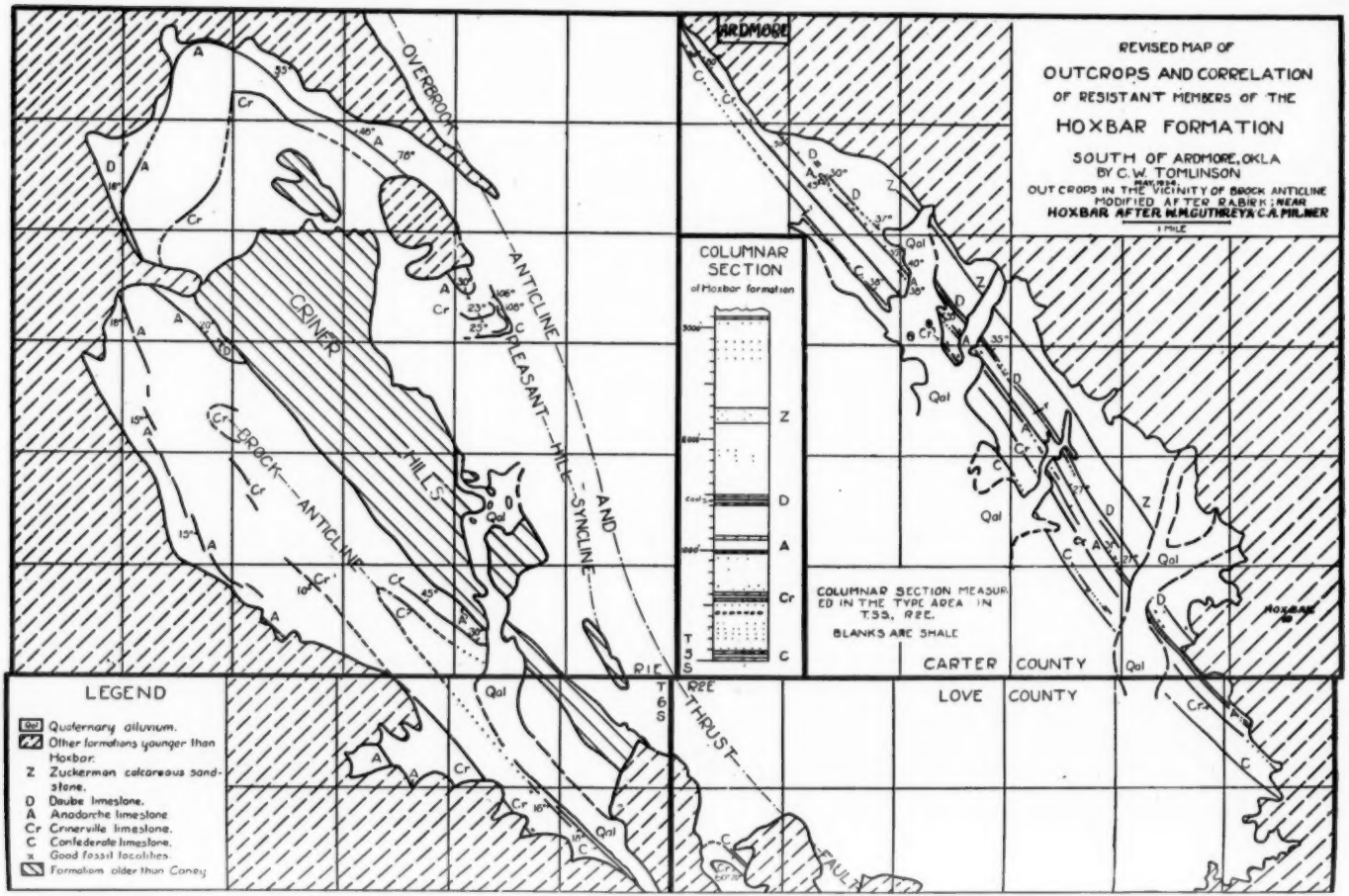
REVISED MAP OF
OUTCROPS AND CORRELATION
OF RESISTANT MEMBERS OF THE
HOXBAR FORMATION
SOUTH OF ARDMORE, OKLA
BY C. W. TOMLINSON
1934-1936
OUT CROPS IN THE VICINITY OF BROCK ANTICLINE
MODIFIED AFTER DARTON NEAR
HOXBAR AFTER N.M. GUTHREY & C.A. MILNER
1 MILE
ARDMORE
OVERBROOK
ANTICLINE
CRINER
HILLS
BROCK
ANTICLINE
PLEASANT HILL SYNCLINE
AND
COLUMNAR
SECTION
of Hoxbar formation
Z
D
A
Cr
C
COLUMNAR SECTION MEASURED IN THE TYPE AREA IN T.3S., R.2E.
BLANKS ARE SHALE
CARTER COUNTY
LOVE COUNTY
HOXBAR
THRUST
FAULT
LEGEND
Qal Quaternary alluvium.
Other formations younger than Hoxbar.
Z Zuckerman calcareous sandstone.
D Deube limestone.
A Anadarche limestone
Cr Crinerville limestone.
C Confederate limestone.
x Good fossil localities
Formations older than Caney

FIG. 1.

prepared of the area of Pennsylvanian rocks east of Berwyn and north of Washita River, where there are exceptionally fine exposures of many of the highly fossiliferous members of the Dornick Hills formation, and of the lower Deese, affording excellent opportunity for collecting.

According to the revised mapping, the Confederate limestone member, described in *Bulletin 46* as the basal unit of the Hoxbar formation, is traced southeastward *into* instead of below the Westheimer member as mapped west of Hoxbar, near the south line of Carter County. As the Westheimer is still believed to have been correctly correlated between the four areas in which it was identified on Plate XX of that bulletin (the Hoxbar area, the Pleasant Hill syncline northwest of Overbrook, the syncline just south of Overbrook, and south of the Criner Hills), this name can now be dropped and the name Confederate (geographically preferable) be substituted.

This places the base of the Confederate limestone member in the type area of the Hoxbar formation slightly higher than the base of that formation as originally mapped by Goldston.[2] However, as this member is in that area the lowest of the conspicuous limestones which here constitute the most essential distinguishing characteristic of the Hoxbar formation as compared to the formations above and below it, and also includes the lowest limestone conglomerate (possibly intraformational) above the Bostwick member of the Dornick Hills formation, it appears most appropriate to continue to regard the base of the Hoxbar as coincident with the base of the Confederate limestone member.

The detailed mapping has revealed 15 distinct limestone or sandy limestone members of the Deese formation, some of them very fossiliferous; but thick massive sandstones and chert-pebble conglomerates remain the outstanding conspicuous lithologic types most characteristic of the Deese outcrops.

A corollary of the correction in mapping of the Confederate member is the identification of the Union Dairy member of the Hoxbar formation with the Crinerville limestone member, which in *Bulletin 46* was not positively identified southeast of Ardmore. As the name Crinerville has been in current use for many years with definite geographic significance, it is to be preferred to the name Union Dairy, which has never been in general use as a geographic name, and is therefore dropped.

It is reported by White[3] and others that unpublished microscopic paleontological data confirm this correlation of the Union Dairy limestone with the Crinerville limestone member of the Hoxbar.

Similar detailed mapping has not yet (at time of writing) been extended to cover the area north of Ardmore. Positive identification therefore has not yet been made of individual members of the Hoxbar there. Even the Arnold member of the Deese, so well developed in the type area northwest of Ardmore, has not been traced around the Caddo anticline into the Berwyn area. The member marked as Arnold on Plate XVIII of *Bulletin 46* in Sec. 15, T.3 S., R.2 E., has been traced south-southwest into a position stratigraphically much higher than the member so marked in Section 28 of the same township; therefore the broken line connecting the two on that plate should be disregarded. The upper of the two is probably the true Arnold.

C. W. TOMLINSON

ARDMORE, OKLAHOMA
May 29, 1934

[2] W. L. Goldston, Jr., "Differentiation and Structure of the Glenn Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 6, No. 1 (January–February, 1922), pp. 5–23.
[3] M. P. White, oral communications.

## RÔLE OF CAP ROCK IN OIL ACCUMULATION

Under the foregoing title, R. P. Lockwood recently presented in this *Bulletin*[1] a description of experiments which he conducted, the results of which he believes constitute proof that oil can not accumulate beneath an impervious cover if the sand is saturated with water. It seems that Mr. Lockwood has either ignored, or at best so imperfectly evaluated, numerous important factors that his conclusions have little or no weight.

In general it may be stated that he has failed (1) to describe adequately the detailed procedure in his experiments. For instance, it is necessary to read far into his article, before one discovers with certainty the method of entrance and exit of the oil-water mixture, and even then it is by no means clear whether conditions were uniform in all his experiments. Again, no definite data are presented regarding the linear rate of movement of the fluid through the apparatus, and in some of his experiments, no information at all is given relative to this subject. Neither can this rate be computed, because of lack of the necessary specific data regarding the scale of his apparatus. Further, though Mr. Emmons is definitely quoted to the effect that heat aided in accumulation, in the work done at Minnesota, yet Mr. Lockwood neglects to state whether any similar test was made during his own experiments. Nor is there sufficiently specific information as to the extent to which gas was used in the procedure, and as to its effect if it was used.

Again, he has failed (2) to be sufficiently definite or accurate in statements of certain more general principles. To be more specific, his references to pressure fail to distinguish adequately the relative significance of the effects of simple compression and differential pressure, both of which should be considered, in any complete analysis of the problem. His acceptance, also, of the conclusion by Rogers regarding the variation of the sulphur content with depth does not seem to be in conformity with actual observations.

Further than this, Mr. Lockwood fails (3) to present his results in systematic form, showing that each is a definite and necessary conclusion drawn from a specific experiment.

Again, he fails (4) to present any field evidence to substantiate his conclusions, or to make any effort to show that his materials or methods of procedure conform to known field conditions.

And finally (5) his conclusions are far more sweeping than are justified by the experimental work described.

It is the purpose of this discussion to point out in some detail several of the more important factors that have been overlooked or inadequately evaluated, with an attempt to analyze the implications involved in each.

*Entrance and exit conditions.*—One point that merits careful analysis stands out conspicuously in the paper. This is the method of introducing the oil-water mixture into the structure, and the method of exit of the overflow. Mr. Lockwood says, "The apparatus is so constructed that fluids can be admitted through the bottom of either limb, or directly beneath the crest, or from the under side of one limb." From this, one would expect a careful analysis of the comparative results from each mode of introducing the fluid. Unfortunately, however, no such discussion is forthcoming. On the contrary,

[1] Robinson P. Lockwood, "Rôle of Cap Rock in Oil Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 7 (July, 1933), pp. 713–31.

he states in another paragraph that, "In these experiments, the oil was forced to make a vertical entrance into the reservoir sand." In spite of the fact that the apparatus was capable of several types of entrance, the one was chosen which is *most unlike* the true conditions in an oil field, and the others were ignored.

Regarding the opening shown at the apex of the anticline, he says, "The opening on the crest acted as an escape for air driven from the sand." This sounds logical enough, and one would assume that once the air was driven out, this exit would be closed. But when one turns to Figure 6 of his paper this natural assumption is dispelled. This figure shows that the opening on the crest is used by Mr. Lockwood as the point of exit or overflow, for his excess fluid. This he also states when he says, "Only a small percentage of the oil emerged through the overflow tube on the *crest* of the anticline."

Does Mr. Lockwood expect a group of geologists to believe that these conditions in any way reproduce those of an actual anticlinal reservoir in nature? Does he mean to tell us that he actually thinks the chief movement of the oil-water mixture in an oil pool is vertically upward through the strata?

Inasmuch as no sedimentary rocks are wholly impervious, there is doubtless everywhere some flowage across the stratification and it is entirely possible that this movement across the strata may in some measure result in the differential separation of oil and water. But surely no geologist with practical experience in subsurface conditions can doubt for a moment that the chief flowage is concentrated along certain relatively permeable layers, parallel with the bedding.

In fact it seems almost impossible to believe that, with such an arrangement of his equipment, Mr. Lockwood could have seriously expected accumulation in the first set of experiments, where the only cover was the glass tube. Unfortunately, he makes no definite statement, and it is only the second set of experiments that gives the clue to this procedure. It would be most interesting to know whether he actually followed the same course, with respect to overflow, in the first set, as he clearly did in the second.

How could one expect accumulation at the crest of an anticline, when the crest was actually open, and permitted the free escape of all fluids? There could have been little if any more accumulation in the second set than in the first, if the hole used as an overflow had penetrated the pervious cover of the second as it did the impervious cover of the first.

For any real test of a dynamic system, the oil-water mixture should be introduced at the lower end of one limb, should flow along the reservoir rock parallel with the bedding and have its overflow at the opposite limb. The overflow should be higher than the crest of the anticline in order to preserve complete saturation at all times, but must be separated from it by an intervening syncline, so that the oil after its entrance can not move continuously upward to an exit.

*Temperature factor.*—In spite of the Emmons statement that no accumulation was secured until after the entire system was warmed, Mr. Lockwood still fails, first, to indicate whether he himself made any effort to test the effect of this factor; second, to discuss in any way the probable effect of this factor if applied to his own type of system; and third, to consider the probable presence or absence of this factor in natural accumulation.

The writers believe that this is a most potent element overlooked by Mr.

Lockwood in his comparison of the two sets of experiments. A pertinent fact regarding its possible importance is illustrated by observations on water flow conducted by Slichter,[2] who says

> a change from 50° to 60° increases the capacity to transmit water under identical conditions by about 16 per cent, while a change from the freezing temperature to a temperature of 75° will nearly double the power of a soil to transmit water. This difference, of course, is not due to any change in the soil itself, but is due solely to the increased ease with which water flows at high temperatures compared to the ease with which it flows at low temperatures.

The physical properties of oil are much more sensitive to temperature changes than those of water. That this can not help being a highly important factor in natural accumulation is at once evident when one considers the normal geothermal gradient. It is a well known fact that rock temperatures rise about one degree for each 100 feet of penetration below the earth's surface. In some areas, to be sure, the rate of increase is less than this, but in others it is greater.

For a depth of 2,000 feet, this would mean a rise of about 20°; for 10,000 feet, an increase of 100°. Nor must it be forgotten that most of our oil sands have, at various times in their history, been much more deeply buried than at present, and consequently subject to even greater temperature increases. It is felt that if a reasonable effort had been made to apply heat, and study the resultant changes, the outcome of Mr. Lockwood's work might have been very different.

*Gas as a factor in accumulation.*—In most of the experiments there is no reference to gas; hence, one would seem to be justified in assuming that none was used.

Much has been written on the influence of gas and gas pressure in aiding migration, particularly as it applies to problems of recovery. The subject is one of great interest and of direct bearing on the field under investigation, and Mr. Lockwood's failure to consider its applications is unfortunate. In view of the fact that the quantity of gas which can be dissolved in a given amount of oil is a direct function of pressure, and that this, in turn, directly controls the mobility of oil, his initial statement that "pressure is of relative value only, and that its elimination in no wise alters the fundamental processes of accumulation," is apparently unsound.

*Static versus dynamic systems.*—Mr. Lockwood is at some pains to point out that in his own work the oil-water mixture was continuously introduced and constantly moving through his apparatus, whereas in the Emmons attempt, the anticline was charged with a sand saturated with an oil-water mixture, and no further material was introduced. His own method he calls the dynamic, the other the static. While he does not specifically point the contrast, one is forced from his discussion to infer that he believes this difference is the chief factor in the differing results attained by the two men. And further, there is reason to feel that Mr. Lockwood considers that the system used in his own work more nearly represents the underground conditions in oil fields. There is considerable reason to doubt the validity of both these inferences.

In the first place, there are at least two other important differences be-

[2] C. S. Slichter, "Field Measurements of the Rate of Movement of Underground Waters," *U. S. Geol. Survey Water Supply Paper 140* (1905).

tween the procedures of the two men, either or both of which are probably of greater significance than the type of system used. These are the factors of temperature and of gas.

In the second place, evidence is available which suggests strongly that the rate of movement of ground water in the oil fields is more nearly approximated by the static system of Emmons than by the dynamic system of Lockwood.

Unfortunately, Lockwood leaves much to the imagination, regarding the rate of flow of the fluid through his apparatus. In only one of the several experiments does he give any information on this subject. Nor is the one in which data are available a major one. It refers to conditions beneath a small inverted watch glass, not to his work with anticlines and terraces. In this case he describes the delivery as at the rate of 250 cubic centimeters per hour and at 1,500 cubic centimeters per hour. However, he does not give the diameter of the delivery tube, so that it is impossible to compute the actual linear rate of movement.

In spite of this, it may be rather illuminating to examine available data concerning the known rate of movement of ground water through sands in nature. The work of Slichter[3] affords interesting information. At various places in alluvial fans and sand plains, he drove numerous shallow wells. Into the upper one, in each experiment, he introduced a detector solution, and observed the time it took to reach each of the other wells. The rate of movement varied widely, from a minimum of a few inches, to a maximum of 96 feet in 24 hours. The three highest rates observed were 52, 77, and 96 feet, and these were all considered very abnormal. With these three exceptional cases omitted, the average of the other 30 observations gave a rate of about 5 feet in 24 hours.

It must be understood that all these measurements were made in unconsolidated surface sands and gravels, where conditions for rapid movement are ideal. In deeply buried and well cemented sandstones, the factor of cementation would afford a considerable obstacle to the rate of flow, and it should be much slower than that for loose sands and gravels.

In a highly pervious and but slightly cemented aquifer, such as the so-called Potsdam sandstone of Wisconsin, Van Hise[4] has estimated a rate of flow of about 0.75 kilometer a year, or about 6.5 feet per 24 hours. This, at best, is only an estimate, but is not far from the figure secured by Slichter. In his discussion, however, Van Hise says, "The average length of time during which the water remains in the ground would probably be longer, perhaps much longer, than calculated," thus indicating his belief in an average rate far slower than that obtained in his computations. Very few of the well known oil sands of the Mid-Continent field are as coarse, as uniform in grain size, or as weakly cemented as the Potsdam, and it is certain that the rate of flow through them would be much less than even Van Hise's modified estimate.

A particularly illuminating contribution on this subject was recently made by E. O. Meinzer, of the United States Geological Survey, in his paper presented at the Dallas meeting of the Association in 1934, in which he estimated the average linear rate of flow in the Carrizo sand of Texas as prob-

[3] *Op. cit.*

[4] C. R. Van Hise, "A Treatise on Metamorphism," *U. S. Geol. Survey Mon. 47* (1904), pp. 585–86.

ably not greatly exceeding 50 feet per year. The following quotation is from a letter in which he has kindly summarized his results.[5]

> The average linear rate of flow of water in the Carrizo sandstone into the heavily pumped area in Dimmit and Zavala Counties, Texas, is about 50 feet a year. This rate of flow is computed from the average permeability as determined from both laboratory and field tests, the effective porosity as determined by laboratory tests, and the hydraulic gradient measured in the field.

This rate of flow was determined after the development of heavy withdrawal for irrigation purposes. In this connection it must not be forgotten that the significant rate of flow which applies in the accumulation of oil in nature is that which occurs before the original balance of forces has been disturbed by drilling artificial openings into the sand. That this rate must have been, on the average, extremely slow, is also indicated by the fact that the waters associated with the oils in most fields are typically brines. If these are connate waters, trapped many millions of years ago, as their composition appears to indicate, then continuous supplies of fresh meteoric waters at the remote intake would have long since flushed out the saline waters, unless the movement were almost infinitesimally slow, and possibly at many times interrupted by long periods of no movement at all.

In view of these facts, it is probable that any measurable rate used in experimental work would be much greater than obtains in nature. Therefore it is not at all improbable that the static system of Emmons more nearly represents the actual conditions of oil-field accumulation than does Lockwood's dynamic system.

*Time factor in accumulation.*—The only recognition accorded to this factor is the statement that if the oil is left in the system for several days it becomes so viscous that it will no longer migrate. This condition is ascribed chiefly to oxidation of the oil. Mr. Lockwood gives the impression that the increased viscosity rules out any time factor as a real element in the problem. Again, however, he gives no consideration to the possibility that time may be a more vital matter in nature than it seems to be in the laboratory experiment. Active oxidation is hardly to be expected at the depth of most natural accumulation; therefore, it is a far less important obstacle in the field than in the laboratory.

There is, however, another factor that might produce viscosity in oils, namely, the known reactions between the hydrocarbons and water. The mere fact, however, that oil has actually accumulated in enormous quantities in deep reservoirs is in itself proof that this possible factor has afforded no serious obstacle to migration. Except in very limited areas underground, the great bodies of oil show no evidences of having been rendered unduly viscous by this or by any other process.

If we are correct in our estimate of the slow rate of movement of ground waters, then the possible time factor must of necessity become more important than in laboratory experiments. With a much longer time available for the final separation of the oil and water than can possibly be employed in the laboratory, and without the danger of the inhibiting power of increasing viscosity, there is reason to believe that the segregation of oil and water would be much more complete than could be hoped for in any experimental set-up.

[5] E. O. Meinzer, personal communication.

*Pervious versus impervious cap rock.*—The impervious cap rock to which reference is made in the paper under discussion consists of glass tubing. Mr. Lockwood offers no comment regarding the degree of permeability of artificial glass compared with that of the various types of strata in nature which might play the rôle of retaining covers favoring oil accumulation. One must assume, however, in the absence of any comment, that Mr. Lockwood believes that at least some of the beds in nature approximate the imperviousness of glass, else there would be no point to his experiments and the resulting discussion. Geologists well know, however, that the only rocks in nature comparable with glass in this respect are those of igneous origin, and these are so rare in most oil fields as to merit little consideration.

*Summary.*—By way of brief summary it is desirable to point out that Mr. Lockwood's impervious glass cap rock has no counterpart in nature, and that his mode of ingress and egress of the mixture is contrary to well known conditions in oil fields. In addition it should be stressed that numerous highly significant factors in the problem have either been treated inadequately, or apparently ignored. Among these are available time, rate of flow, pressure, gas content, and the influence of heat. It is still conceivable that a somewhat previous cap rock may aid accumulation, but the validity of his conclusion that it can not occur except under such conditions is certainly not established by the inadequate evidence he presents.

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MISSOURI SCHOOL OF MINES, ROLLA, MISSOURI
May 7, 1934

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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# REVIEWS AND NEW PUBLICATIONS

*Deutsches Erdöl, II* (Petroleum in Germany, II). By A. Moos, H. Steinbrecher, O. Stutzer. Ferdinand Enke, Stuttgart (1934). 98 pp., 8 illus. Price, 9.80 RM.

The small book comprises three papers.

1. "Chemical Investigation of German Crude Oil and Interpretation of It According to Depth and Geologic Formation," by Professors Stutzer and Steinbrecher. New samples of crude oil were collected; 13 from the Lower Cretaceous, 3 from the Upper Dogger, 4 from the Lower Dogger, 7 from the Rhaetic and Lower Lias, and 1 from the Schilfstein. Analyses were run according to the same standard method. The gravity of oil in each stratigraphic horizon increases with depth; the gravity of the crude oil from the Upper Dogger and Lower Cretaceous is distinctly heavier than that of the Lower Dogger and older horizons; but the crude oil in the Lower Dogger is lighter than that in the three older horizons. The asphalt content does vary much with depth; but the variation is distinctly greater in the Upper Dogger and Lower Cretaceous oils than in the Lower Dogger and old oils. In the quantity of distillate which comes over (1) below 150° C. and (2) below 300° C., the crude oils from the Lower Dogger and older horizons give better yields even at depths of 100–200 meters than the crude oils from the Upper Dogger and Lower Cretaceous even at depths as great as 900–1000 meters; and the yield from the crude oil from the Lower Dogger is distinctly greater than that from any of the other horizons.

2. "The Oil Well Borings in the Northern Rhine Valley Graben near Bruchsal 1921–1926," by Dr. Moos. Ten oil tests were drilled to depths ranging from a few hundred to 700 meters; and 130 borings were put down, some of them to depths of more than 70 meters, north of Karlsruhe Baden in the Rhine graben near its edge. The results of the exploration give many new data in regard to the structure at the edge of the graben (normal faults dipping westward) and in regard to the stratigraphy (Cyrenian marl, Meletta beds, Septarian clay, Pechelbronn series, Green Lymnaean marl, Eocene clay, Dogger). Showings of oil were obtained in the Meletta beds, in the Lymnaean marl, and in the Lower Muschelkalk.

3. "What is Your Thought? Was the Mother Substance of the Oil Which is Produced in Hannover Deposited in the Mesozoic, or Did the Oil Originate from the Zechstein?" This is the question put by Professor Stutzer to many geologists who are familiar with the oil geology of North Germany. The following geologists believed strongly in, or inclined strongly toward, the theory of the Zechstein origin of the oil: Bentz, Krejci, Moos, van der Gracht, Murray Stuart, Erb, Hudorn, Schleh; toward primarily a Mesozoic origin: Barton, Borger, Fath, Hermann, Kauenhowen, Schöndorf, Sommeler, Weigelt, Wunstorf, Romanes, Illing, Lees, Clapp; agnostic: Kumm, Kraiss.

The second paper gives new interesting and valuable data on the stratigraphy and structure of the eastern edge of the Rhine graben.

The first and last papers are important contributions to the subject of the

origin of the North German oil. The first paper gives the first data which really are usable for determining the relative characteristics of the Hannoverian crude oil. Although the samples are too scanty for final conclusions, the data seem to indicate that the oils fall into two groups: (1) the Upper Dogger-Cretaceous, and (2) the Lower Dogger-Rhaetic-Lias-Schilfsandstein, which have separate individualities of character; and in the second group, the oil from the Lower Dogger has an individuality slightly different from the other oils of the group. In the last paper, the English geologists contribute the important thought that in England there certainly is no Permian oil and little evidence of any underlying Paleozoic oil horizons, and that oil shales are of common occurrence in the Lias and are strongly developed in the Kimmeridge clay; that petroliferous indications are developed in the British Wealden (the main Lower Cretaceous production in Hannover is from the Wealden) and in other British counterparts of shale horizons in the Jurassic and Lower Cretaceous in Germany. Although the data are not finally conclusive, the weight of the evidence is strongly against the derivation of the Hannover oil as a whole from the Zechstein.

DONALD C. BARTON

HOUSTON, TEXAS
June 13, 1934

*The Deformation of the Earth's Crust.* By WALTER H. BUCHER. Princeton Univ. Press, Princeton, New Jersey (1933). xiii+518 pp., 100 figs. Cloth. Price, $5.00.

This volume, according to the preface, is an inductive approach to the problems of diastrophism. The chapter headings are as follows: The Mobile Belts, Isostasy, Continental Margins and Intra-Continental Mobile Belts, The Pattern of the Mobile Belts, The Diastrophic Cycle, Marginal Deformation, Deformation within the Welts, Special Aspects of Orogenic Deformation, The Intrusives, Heterogeneous Mobile Belts and Faulted Belts of Low Mobility, Space Relations of Mobile Belts, Time Relations of Mobile Belts, Epeirogenesis, Summary and Synthesis. Most of the chapters are divided into some half-dozen subheads of which two examples are given here. The chapter on the Pattern of Mobile Belts is divided as follows: (1) The problem, (2) The pattern of modern crustal folds in detail, (3) The pattern of modern crustal folds as a whole, (4) The compound belts of Post-Algonkian orogenesis, (5) The mechanical interpretation of the pattern of crustal folds. The chapter on the Deformation within the Welts is divided as follows: (1) The southern Rocky Mountains, (2) The Bighorn Mountains, (3) The Harz Mountains, (4) The crystalline Appalachians, (5) The Western Alps, (6) Résumé.

Professor Bucher, in this book, attempts to assemble all the essential geological facts of a general nature that bear on the problem of crustal deformation. From these facts he formulates 46 laws and 39 opinions, all of which are carefully worded generalizations. Criticisms of these generalizations are invited by the author. Descriptions of specific areas illustrate the generalizations. Professor Bucher's attempt to formulate a series of generalizations as a basis for a satisfactory solution of geotectonics is praiseworthy indeed and many of his generalizations are of great importance. Some of Professor Bucher's interesting conclusions are: evidence for subcrustal currents is far from satisfactory; there is no conclusive evidence for continental drift;

and his law 41 is "Orogenic movements have frequently taken place simultaneously in widely different parts of the world."

The mobile belts are characterized by elongate narrow uplifts and depressions, the former referred to as "welts" and the latter as "furrows." The welts are thought to arise from compression of the crust due to contraction of subcrustal material, and the furrows are formed under conditions of tension due to expansion of subcrustal material. In contrast to mobile belts, the non-linear areas are called swells and basins. The distribution of the mobile belts over the crust resembles somewhat the distribution of the tension cracks which develop in spherical shells by expansion of the core.

Three types of mobile belts, indicated in the following paragraphs, are recognized, arranged according to their degree of mobility, that is, according to their liability to greater vertical movement. There are gradations between these types or combinations of these types.

Homogeneous Mobile Belts—Alps and Appalachians
Heterogeneous Mobile Belts—Coast Range of California and the folds of North Germany
Fracture Belts of Low Mobility—Rift Valleys of East Africa, Rhine Valley and the Trias belts of Eastern United States

All three types of belts have been subjected to alternating compression and tension. The different types are said to differ primarily in the manner in which the crust yielded under tensional stress. A few of the many points which have led Professor Bucher to postulate an expansion stage are (a) the contrast between the rigid and mobile areas of the crust, (b) the fact that later furrows intersect earlier folded structures at all angles, (c) the presence of thick limestones and fine-grained clastic sediments in the early or geosynclinal phase of the history of a mobile belt which is taken to indicate that some furrows, at least, develop without an accompanying welt, and (d) the rhythm of world-wide emergences and submergences of the continents.

Professor Bucher has informed the reviewer that he regards his compressive stage, which is due to the contraction of subcrustal material, as identical with the classical contraction theory. According to the contraction theory it is the weight and strength of the earth's crust that causes the deformation, as the crust adjusts itself to the smaller area into which it sinks. Some readers may feel that this point was not sufficiently emphasized in this book. The earth's crust in its present state of deformation is apparently essentially in gravitational balance, which strongly suggests that it reached that state of deformation by the force of gravity. The use of the word gravity on pages 261 and 472 is subject to interpretations not intended by the author. Under the contraction theory diastrophism is seen to be the inevitable result of a differentially cooling and therefore differentially contracting, crusted, rotating, revolving earth, whose crust is being deformed by its own weight and differential strength. One of Professor Bucher's objections to the contraction theory as adequate to explain all deformation seems to be that under a permanent state of compression the crust would be expected to yield haphazardly (p. 474). Using the increasing thickness of the crust as well as its strength as a basis, a general cyclic deformation under the contraction theory can be imagined, if the present knowledge of historical geology demands such cycles. The sinking of large areas of the crust, due to relative increase in weight possibly accompanying more rapid cooling, and the consequent lowering of the

sea-level, may be thought of as the epeirogenic phase. The following horizontal adjustments of the continents may be thought of as the orogenic phase, which might be followed by a quiescent stage characterized by base-leveling when the horizontal adjustments had been completed before the epeirogenic phase had again developed.

The expansion stage, due to the expansion of subcrustal material, accompanied by tensional stress in the crust, is the assumption of Professor Bucher about which there will be the most disagreement. Inasmuch as both contraction and expansion are assumptions from a geologic standpoint, both should not be made if one is sufficient and neither should be made unless necessary. The absence of low-angled normal faults with horizontal displacements measured in miles seems to discourage the idea, but probably does not completely rule out the possibility, of attributing deformation to continuous or intermittent expansion without any contraction. It is not certain, however, that all the possible means of explaining deformation, without change of volume of the earth, have been ruled out, but the temporary assumption of contraction may be partially justified by the evidence from the thermal condition of the earth which suggests contraction on grounds quite independent of the evidence of structural geology. Probably most geologists adopt some form of the contraction theory. Doubtless many modifications of the contraction theory remain to be discovered and particularly the evaluation of the effects of radioactivity, but subcrustal expansion, by its very nature, must be the last resort. If there is other evidence, possibly astronomic or thermodynamic, that indicates expansion of the globe, an assumption of subcrustal expansion is justifiable. But since non-geologic evidence for expansion is even less conclusive than evidence for contraction, it seems desirable to attempt to explain deformation by contraction without intermittent expanding stages. Reading this book has given the impression that subcrustal expansion was assumed by the author without completely exhausting the possibilities of the classical contraction theory. Instead of the mobile belts differing primarily in the manner in which the crust yielded under tensional stress, there seem to be other possibilities. Some such possibilities, apparently not completely disposed of in the book, will here be mentioned.

The mobile belts may be thought of as differing primarily in the direction of compression and the direction of elongation due to that compression. The correlation of strain with stress in the earth's crust is a complex, unsolved problem, but assuming that elongation is at right angles to the major compressive stress is a convenient way of thinking about it. Homogeneous belts with great vertical movement suggest horizontal compression with the elongation in a vertical direction. Belts of low mobility may be produced by vertical compression with the elongation in a horizontal direction. Such compression may develop over igneous intrusions or incompetent material which are lifting the overlying strata in their ascent or in areas which are being arched due to the sinking of adjacent heavier areas. Heterogeneous belts may be formed by horizontal rotational stress with the elongation in a horizontal direction but tending to be parallel with the belt instead of at right angles to it as in belts of low mobility. Subsequent vertical displacements may occur along the resulting more or less vertical *en échelon* flaws. When the direction of relief to horizontal compression is upward, welts are formed and when the relief is locally downward, due to local increase in

weight possibly accompanying more rapid cooling at depth, furrows may be formed. During horizontal rotational stress the direction of elongation may be vertical instead of horizontal, due apparently to the relative dimensions of the material which is being deformed by the horizontal rotational stress. Under such conditions *en échelon* welts may be formed when the direction of relief is upward. When the relief is downward *en échelon* furrows might form. The rotational character of the horizontal compression presumably depends on the relative orientations of the directions of relief and compression. The bending downward of the crust may be accompanied by the formation of local tension cracks in the crust at the points of greatest curvature in which igneous activity might develop. The horizontal tension thought to exist below the theoretical level of no strain of the crust would be locally changed to horizontal compression which might force igneous material to and above the surface. It seems possible that, when the local horizontal compression near the surface is sufficient, furrows might be forced downward, out of gravitational balance, that is, they would be forced farther downward than the crust would have sunk due to its increased weight. At such depth the crust would cease to increase in weight more rapidly than that of adjacent areas and the direction of relief to horizontal compression would eventually become upward and large-scale overthrusting, with backward thrusting, could take place. The formation of an asymmetric furrow would be analogous to the formation of an asymmetric welt and presumably the condition of greatest tension and therefore liquefaction or igneous activity would be on the steeper side of the asymmetric furrow. When overthrusting took place the condition of tension would cease and the igneous material which had not already solidified by cooling would be pressed against the country rock and solidified. From such a point of view asymmetric furrows would be expected to fail by overthrusting of the steeper limb of the furrow. The formation of an asymmetric furrow would probably be accompanied by the rising of a welt adjacent to the steeper limb of the furrow and if this welt rose above sea-level the history of the region would be modified by erosion and deposition. Basic igneous material might enter the resulting geosyncline. A number of large-scale features on the earth's surface may be accounted for by east-west tension and north-south compression. Meridional compression with east-west tension in temperate and equatorial latitudes might result from an increase in oblateness accompanying a slight increase in the rate of rotation of the earth, possibly due to its contraction. Deformation under such circumstances might result in tension fracture zones with more or less meridional trend such as the African Rift zone; or northeast and northwest trending vertical shears or flaws. The major horizontal movement, which should be relatively southward on the east side of the northwest flaws and on the west side of the northeast trending flaws, would probably be due to the meridional compression. The San Andreas flaw, in California, may represent such a northwest trending vertical shear and the diagonal trends of the borders of continents may owe their position to former flaws of similar origin. Mediterraneans may owe their inception to the intersection and offset of such flaws and their development to north-south compression augmented by compression due to sinking. In many places the meridional compression is evidently masked by compression due to sinking, but apparently not in California, where the east-west ranges and the diagonal ranges may be thought of as representing dif-

ferent directions of vertical elongation resulting from the same meridional compression. The different directions of vertical elongation may be due, in part, to the orientation and dimensions of the less competent parts of the region.

In Professor Bucher's tension stage he has not assumed meridional compression and in his discussions of tension there is usually the reasonable assumption that vertical compression is greater than horizontal compression. If there should be an adjustment to the possible change in the rate of rotation of the earth, accompanying expansion, presumably it would be just the opposite to that of a contracting globe. The rate of rotation would slightly decrease, the oblateness decrease, and there might be meridional compression, but the horizontal relief would be at high latitudes where radial tension cracks might form, or, since vertical compression would probably be greater than horizontal compression at the poles, grabens or furrows might form, arranged more or less concentrically to the poles. The changes in the rate of rotation, here suggested, are assumptions which may be unnecessary. If rotation is ignored it seems reasonable to expect that the direction of elongation of an expanding oblate crusted spheroid would be polar, and perhaps also, the direction of elongation of the crust of a contracting oblate spheroid would be equatorial.

The book is well written and some of the descriptions of specific areas are very interesting and there is a host of references.[1] In fact, from the standpoint of one who views with alarm the rising tide of expansionists, the book is too well written. It is well illustrated, but some of the illustrations have apparently suffered in reduction. The attempt to outline crustal deformation, with as much system as present knowledge seems to permit, as 85 generalizations (46 laws and 39 opinions) is probably the outstanding contribution of this book. While the discussion of the contraction theory and the interpretation of tension do not seem entirely satisfactory, this book may come to have a great influence on geologic thought because it brings to the attention of many geologists the major problems of geotectonics.

RALPH STEWART

WASHINGTON, D. C.
May, 1934

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## RECENT PUBLICATIONS

### CALIFORNIA

"Geologic Map of Kettleman Hills, California." Advance edition of the geologic and surface map that will accompany a report on the geology and oil resources of the Kettleman Hills now being prepared by W. P. Woodring, Ralph Stewart, and R. W. Richards. Scale: 2 inches to the mile. Apply to: Director, U. S. Geol. Survey, Washington, D. C. Price: $0.25.

[1] For the Coast Ranges of California at least one more reference should be added: George D. Louderback, "An Outline History of Earth Movements in the Central Coast Region of California in Late Pliocene and Post Pliocene Time," *4th. Pac. Sci. Cong. 2 B, 1929* (1930), p. 841–47.

GENERAL

"Geologische Studienreise in nordamerikanischen Erdölfeldern" (Geological Trip through North American Oil Fields), by A. Bentz. *Petrol. Zeits.* (Berlin), Vol. 30, No. 22 (June 1, 1934), pp. 1–16; 16 figs. First of a series reporting on areas visited on the excursions of the 16th International Geological Congress in June and July, 1933.

The Generalized Geologic Section across the United States on the 39th Parallel, exhibited at the meeting of the 16th International Geological Congress in Washington, July, 1933, has been reproduced, same size. Printed on chart paper in 6 sheets, 27 inches wide, and when trimmed and pasted together, is 18 feet long.

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GEOPHYSICS

"Elektrisches Kernen: seine Anwendung in Rumänien in Jahre 1931–32" (Electrical Coring: Its Use in Rumania in 1931–32), by C. and M. Schlumberger. *Intern. Zeit. f. Bohrtech, Erdölberg. und Geol.* (Vienna), Vol. 42, No. 11–12 (June, 15, 1934), pp. 75–84; 12 figs.

GERMANY

"Erdöl, Kohle, und Bitumina des Wealden in Nordwest-Deutschland und ihre genetischen Zuzammenhänge" (Petroleum, Coal, and Bitumen of the Wealden in Northwest Germany and Their Genetic Relations), by Heinrich Müller. A sedimentary petrographic study. *Oel und Kohle* (Berlin), Vol. 2, No. 4 (1934), pp. 149–51; 3 figs.

RUSSIA

"Geological Explorations in the Southwestern Part of Sheet 93 (Sar)," by M. M. Tolstikhina. *Bulls. United Geol. and Prospecting Service U.S.S.R.* (Leningrad), Vol. 51, No. 99 (1932). 9 pp. Folded geological map of region of Saraninsk Works and geological profile section along Ufa River from mouth of Bulmazy Valley to Mount Severnaia. In Russian, with 1-page English summary. Upper Carboniferous beds are divided into 4 horizons, lithogically and faunally.

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# THE ASSOCIATION ROUND TABLE

## MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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# AT HOME AND ABROAD

## CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CHARLES T. KIRK, J. D. MCCLURE, and ROY A. PAYNE, have been temporarily engaged in work for the United States Geological Survey in Oklahoma.

W. H. COURTIER, of Pittsburg, Kansas, received the degree of Ph.D. in geology from the University of Kansas last June. His thesis was "Physiography and Geology of South-Central Kansas."

IONEL I. GARDESCU, consulting petroleum engineer and geologist, may be addressed at Box 467, Houston, Texas.

JOHN L. RICH, of the geological faculty of the University of Cincinnati, is at Ottawa, Kansas, during the summer.

MARION H. FUNK, of the geological department of the Sun Oil Company, is stationed at McAllen, Texas.

ROBERT E. KING was recently employed by the Magnolia Petroleum Company and is stationed at Midland, Texas.

The officers, executive committee, and members of the Division of Geology and Geography, National Research Council, for the year beginning July 1, 1934, are as follows: chairman, EDSON S. BASTIN; vice-chairman, W. L. G. JOERG; executive committee, EDSON S. BASTIN, W. L. G. JOERG, W. H. TWENHOFEL (retiring chairman), E. C. CASE, NEVIN M. FENNEMAN, and THOMAS B. NOLAN; representatives of societies: DONALD C. BARTON and E. C. CASE, Geological Society of America; W. F. FOSHAG, Mineralogical Society of America; AUGUST F. FOERSTE, Paleontological Society; NEVIN M. FENNEMAN and C. F. MARBUT, Association of American Geographers; W. L. G. JOERG, American Geographical Society; THOMAS B. NOLAN, Society of Economic Geologists; R. S. KNAPPEN, American Association of Petroleum Geologists; members at large, EDSON S. BASTIN, MARK JEFFERSON, and MORRIS M. LEIGHTON. Communications intended for the chairman of the Division should be addressed to him at the National Research Council, Washington, D. C.

The Eighth Annual Field Conference of the Kansas Geological Society will be held on September 1, 2, and 3, 1934, in southwestern Kansas and the adjacent parts of Colorado, New Mexico, Oklahoma, and Texas, as announced by the field conference committee composed of W. A. VER WIEBE, GLENN WOOLLEY, and L. I. YEAGER. The trip includes exposures of formations belonging to the Cretaceous, Comanche, Jurassic, Triassic, and Permian systems. The following stops will be made: (1) Darbyshire structure; (2) Two Buttes dome, where a section from the Permian up to the Dakota is seen as well as igneous rock; (3) deep well drilled at Pipe Springs by Continental Oil Company; (4) deep well drilled at Table Mesa by Continental Oil Company; (5) one of the domes on the Animas arch in which Permian rocks appear at the surface; (6) the Purgatoire dome, which reveals a magnificent

section from the Permian up to and including the Dakota sandstone; (7) Mt. Capulin volcanic cone and associated extrusive rocks; (8) exposures of Triassic to Upper Cretaceous along Cimarron River; (9) clastic plugs and dikes; angular unconformity between the Jurassic and Triassic rocks; and (10) Carrizo Canyon. The registration fee will not exceed $10. For application forms and other information, write to Harvel E. White, Kansas Well Log Bureau, 412 Union National Bank Building, Wichita, Kansas.

SHERIDAN A. THOMPSON, geologist for the Magnolia Petroleum Company, has been transferred from Shreveport, Louisiana, to Dallas, Texas.

A. W. LAUER has changed his address from 1235 East Thirtieth Street, Tulsa, Oklahoma, to 1043 Lincoln Place, Boulder, Colorado.

CARL F. BARNHART, formerly with the Gypsy Oil Company, is now with the Geophysical Research Corporation, Drawer 2040, Tulsa, Oklahoma.

JOHN G. DOUGLAS, who has been on the faculty of the University of North Carolina, has resigned that position to accept one with the Venezuela Gulf Oil Company at Maracaibo, Venezuela.

HENRY ROGATZ has changed his address from 124 East Eighty-Fourth Street, New York City, to the Herring Hotel, Amarillo, Texas.

FLOYD HODSON and HELEN K. HODSON, formerly with the Standard Oil Company of Venezuela, at Caripito, Venezuela, S. A., are now with the Paleontological Research Institution, 126 Kelvin Place, Ithaca, New York.

JOSEPH M. PATTERSON, formerly of 1211 N. Eighteenth Street, Kansas City, Kansas, may now be addressed at The Texas Company, Box 524, Corsicana, Texas.

STANLEY R. SAY, who has been in the Nix Hospital, at San Antonio, Texas, since last September, may now be addressed at the Huasteca Petroleum Company, Apartado 94, Tampico, Tamps., Mexico.

The Panhandle Geological Society, Amarillo, Texas, held its annual meeting May 5, 1934, and elected the following officers for the coming year: president, T. C. CRAIG, Phillips Petroleum Company; vice-president, C. C. ANDERSON, P. O. Box 2025; and secretary, W. W. RUSK, Amarillo Oil Company, P. O. Box 637. J. D. THOMPSON, JR. was re-elected A.A.P.G. district representative for the ensuing two-year term.

The National Research Council will be ready to consider further requests for research grants in the fall. Applications should be filed on blanks which will be furnished by C. J. West, Secretary of the Committee on Grants-in-Aid on request, and should be filed with the committee before October 15, 1934. Action upon these applications will be taken toward the end of December.

J. ELMER THOMAS has changed his address from Fort Worth to San Antonio, Texas, and may be addressed at 1139 Milam Building.

STUART MOSSOM, formerly consulting geologist, San Antonio, Texas, is now employed by the Magnolia Petroleum Company and is stationed at that city.

E. W. BRUCKS presented a paper before the San Antonio Geological Society on the evening of July 2, entitled "The Buckeye Field, Matagorda County, Texas.